Missouri Department of Natural Resources
Water Protection Program

Total Maximum Daily Load (TMDL)

for

Tributary to Pond Creek
(now correctly identified as Pond Creek)

Washington County, Missouri

Completed: Dec. 20, 2010
Approved: Dec. 23, 2010

Total Maximum Daily Load (TMDL)
Pond Creek

Pollutant: Inorganic Sediment

Name: Pond Creek (formerly listed as Tributary to Pond Creek)

Location: Washington County

Hydrologic Unit Code (HUC): 07140104-080002

Water Body Identification (WBID): 2128

Missouri Stream Class: Class C Stream[1]

Beneficial/Designated Uses[2]:
- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation – Category B

Size of Impaired Segment: 1.0 miles[3]

Size of impairment within the segment: 0.5 miles[3]

Location of Impaired Segment:
- Starting downstream at SW ¼ SW ¼ Section 35, T38N, R3E (confluence with tributary, WBID 2129), upstream to SW ¼ Section 3, T37N, R3E (King Arthur's Dam)
- On 2008 303(d) List –

	Latitude	Longitude
Upstream	37.9516	-90.682
Downstream	37.9648	-90.676

Location of Impairment within Segment: From King Arthur's Dam downstream 0.5 miles

Impaired Use: Protection of Warm Water Aquatic Life

Pollutant:
- On 1998 303(d) List – Sediment
- On 2002 303(d) List – Nonvolatile Suspended Solids (NVSS)

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[1] Class C streams may cease flow in dry periods but maintain permanent pools which support aquatic life. See 10 CSR 20-7.031(1)(F).
[2] For Beneficial "or Designated" Uses see 10 CSR 20-7.031(1)(C) and Table H.
[3] In the 2004/2006 and 2008 Missouri 303(d) lists, EPA revised the length of the impaired portion of this water body segment from the 0.5 miles originally listed in 1998 and 2002, to the length of the entire WBID 2128 segment, 1.0 miles.

Pollutant (continued):

- On 2004/2006 and 2008 303(d) Lists – Inorganic Sediment
- NOTE: While Pond Creek is not currently 303(d)-listed for cadmium, lead and zinc, it is recognized that these metals in sediment (S) are causing or contributing to toxicity issues in the water body. As a result, TMDLs for cadmium, lead and zinc in sediment and dissolved cadmium, lead and zinc in the water column have been included in this TMDL document.

Pollutant Source: Barite Tailings Pond

TMDL Priority Ranking: Low

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1. INTRODUCTION

This Tributary to Pond Creek Total Maximum Daily Load (TMDL) for inorganic sediment is being established in accordance with Section 303(d) of the federal Clean Water Act. The department is establishing this TMDL by no later than 2010 to meet the milestones of the 2001 Consent Decree, *American Canoe Association, et al. v. EPA*, No. 98-1195-CV-W in consolidation with No. 98- 4282-CV-W, February 27, 2001.

This water quality limited-segment in Washington County has historically been misnamed in Missouri's Water Quality Standards and 303(d) lists as "Tributary to" Pond Creek. Effective Oct. 30, 2009, the name of this water body segment, as listed in 10 CSR 20-7.031, Table H, was changed to Pond Creek in order to agree with how the stream is identified in the U.S. Geological Survey's Geographic Name Information System (USGS 1990; See Figure 1). This discrepancy is further discussed in Section 2.1 of this document and future Missouri 303(d) lists will reflect this correction. As a result, the impaired segment on which this TMDL is developed will be referenced though out the document as "Pond Creek."

This water body segment, formerly known as "Tributary to Pond Creek," in Washington County is included on the U.S. Environmental Protection Agency (EPA)-approved 1998 and 2002 303(d) lists for Missouri as impaired by sediment and nonvolatile suspended solids (NVSS), respectively. The change from sediment to NVSS was to specify that the problem was due to mineral solids (e.g., silt, sand and gravel) coming from eroding mine waste materials and stockpiles. On the 2004/2006 and 2008 303(d) lists, the pollutant, NVSS, was replaced with "inorganic sediment." Since NVSS and inorganic sediment have essentially the same meaning, the listing was changed to inorganic sediment to better characterize the impairment. While the two terms may be used interchangably, the data used to identify the listed impairment has not changed.

Another modification from previous 303(d) listings is a change by the EPA on the 2004/2006 List to include the entire classified segment length of 1 mile as impaired instead of the previous listing of only the upper 0.5 mile (See Figure 1). In the 2008 303(d) List, the 1-mile upper segment of Pond Creek, Water Body Identification (WBID) 2128, is listed as impaired by inorganic sediment from a barite tailings pond (i.e., King Arthur's Lake).

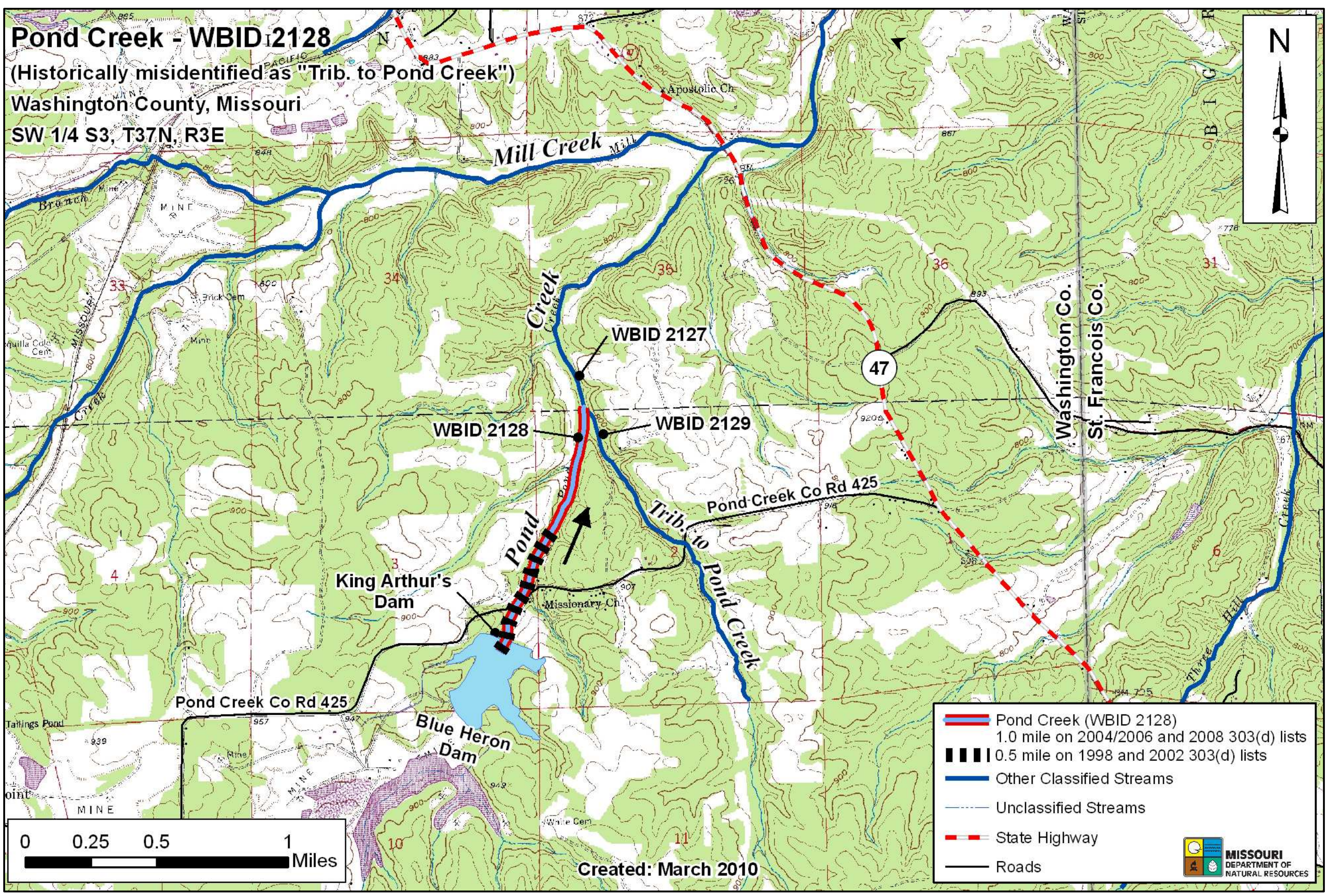
Missouri Water Quality Standards (WQS) include rules associated with designated beneficial uses, water quality criteria and antidegradation. The purpose of a TMDL is to determine the pollutant load a water body can assimilate without exceeding the WQS for the pollutant for which the water body was listed. The TMDL also establishes the pollutant load capacity necessary to meet the criteria established for each water body based on the relationship between pollutant sources and instream water quality conditions. The TMDL consists of a wasteload allocation (WLA), a load allocation (LA) and a margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint sources. The MOS is a percentage of the TMDL that accounts for the uncertainty associated with the model assumptions and data inadequacies. These elements are discussed in detail in Section 6.2 of this document.

2. BACKGROUND

2.1 Geography

Pond Creek is located in the Big River Basin in Washington County, Mo., within the Ozark/Meramec Ecological Drainage Unit[4] (EDU No. 25). The headwaters of Pond Creek are just southeast of Mineral Point, and consist of at least six, small intermittent creeks that flow north into two, large impoundments before converging into Pond Creek. Blue Heron Dam impounds the upper most lake followed almost immediately downstream by the lake impounded by King Arthur's Dam (See Figure 1). From King Arthur's Dam, the impaired, Class C segment (WBID 2128) flows north/northeast for one mile, at which point it is joined by another Class C creek, Tributary to Pond Creek (WBID 2129), which flows in from the southeast. The confluence of those two water bodies marks the uppermost end of the Class P[5] portion of Pond Creek (WBID 2127). The creek continues to flow another 1.3 miles before it's confluence with Mill Creek, which eventually converges with the Big River in extreme northwest St. Francois County.

Figure 1. Pond Creek (WBID 2128) and Tributary to Pond Creek (WBID 2129) as seen on the USGS "Mineral Point" 7.5-minute topographic quadrangle map. (Note that the names of WBID 2128 and 2129 have been historically reversed in Missouri 303(d) lists and Water Quality Standards. Also, King Arthur's Dam, and the lake it impounds, has been superimposed on this figure's topographic map base because the 1982 photo revision of that map neglected to portray their existence, although the dam was constructed in 1980.) ⟶ **Direction of Flow**



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[4] Ecological Drainage Units are delineated drainage units that are described by physiographic and major riverine components.

[5] Class P streams maintain permanent flow even in drought periods. See 10 CSR 20-7.031(1)(F) (MoDNR 2009).

One mile of Pond Creek is listed as impaired by inorganic sediment from barite mine tailings. The two dams, below which the impaired segment begins, were both built to impound water to facilitate washing of mined barite. Blue Heron Dam was first constructed in 1946, and King Arthur's Dam, built in 1980[6] (See Sections 2.5 and 5.1 for more information on the dams). These two dams are located approximately 2 miles due east of the town of Mineral Point, Missouri. The tributary (WBID 2129) that enters Pond Creek one mile downstream from King Arthur's Dam has historically been misidentified in Missouri Water Quality Standards as main stem Pond Creek. As mentioned previously, the impaired segment, on which this TMDL is written (WBID 2128), has been historically misidentified as the tributary in Missouri Water Quality Rules (10 CSR 20-7.031, Table H) and 303(d) lists. As mentioned in Section 1, effective Oct. 30, 2009, the names of these two water body segments, as listed in 10 CSR 20-7.031, Table H, were corrected.

2.2 Population

The population of the Pond Creek watershed is not directly available. However, the population of the watershed can be roughly estimated based on the population of Washington County. Washington County covers an area of approximately 763 square miles and has an estimated population of 24,548 people (U.S. Census Bureau 2008). The largest urban center in Washington County is Potosi, the county seat, with a population of approximately 2,700 people. The next largest communities are Irondale and Mineral Point, both with populations under 500. Because the Pond Creek watershed does not have an urban population, the rural population estimate for the watershed is also the estimated total watershed population. The rural population for Washington County (total population minus total urban population) is 20,844 people. The Pond Creek watershed area is approximately 4.47 square miles. Therefore, the rural population of the Pond Creek watershed is estimated to be 122 people (derived by dividing 4.47 square miles by 763 square miles, and then multiplying by 20,844 people).

2.3 Current Land Use

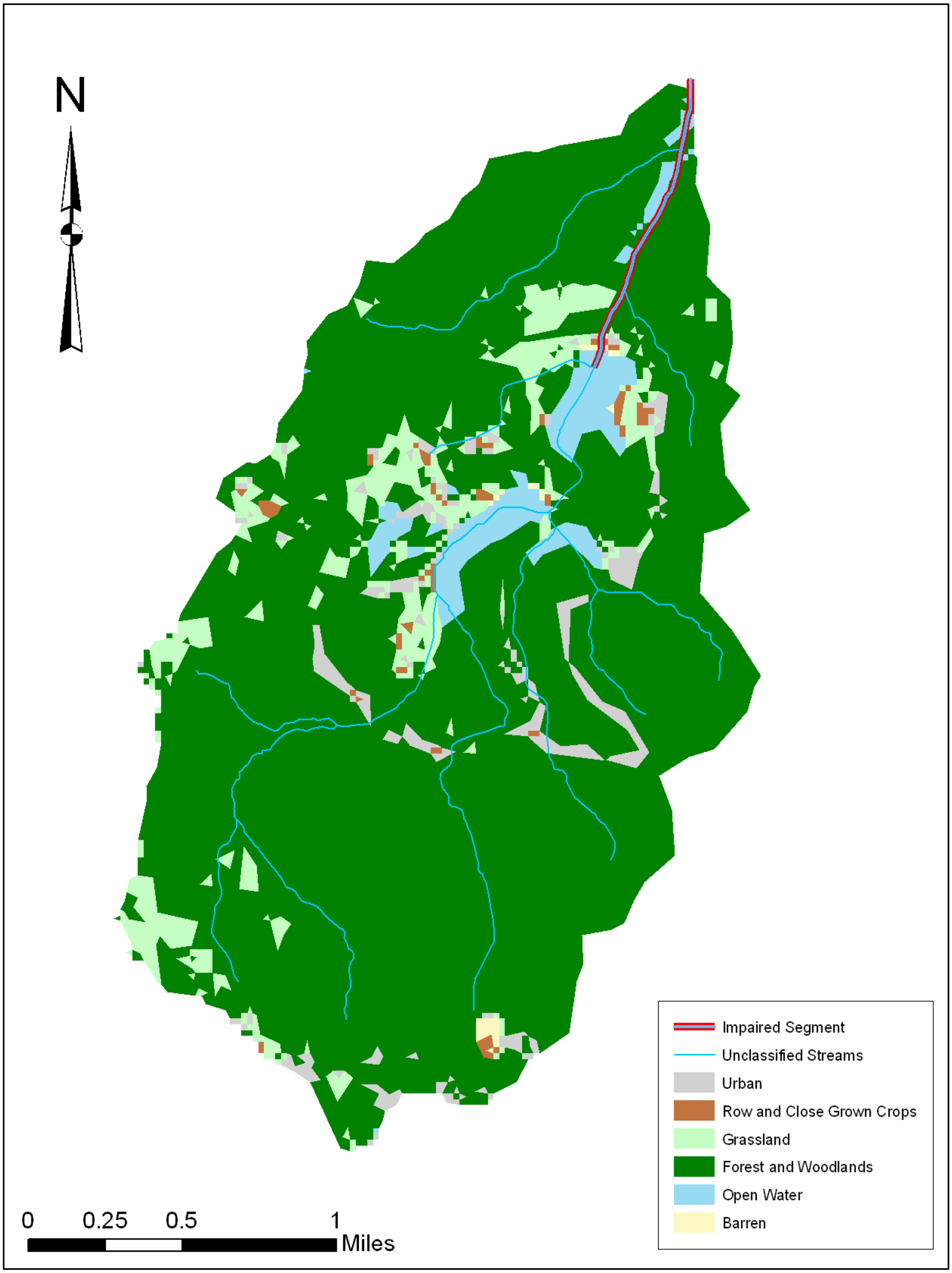
The watershed associated with the impaired segment of Pond Creek is approximately 4.47 square miles. Forest and woodland make up 84 percent of the watershed, with the next highest land use being grassland which accounts for 7.6 percent. Blue Heron Dam and King Arthur's Dam impound the two large reservoirs on upper Pond Creek, and account for most of the 111 acres (3.9 percent) of open water in the watershed (Table 1 and Figure 2). While there are no urban centers in the Pond Creek watershed, urban land use represents areas of impervious cover such as roads and rooftops of buildings (3.3 percent).

Table 1. Land use distribution for the upper Pond Creek (WBID 2180) watershed (MoRAP 2005)**.**

Land Use Type	***Area in Acres***	***Area in Square Miles***	***Percentage***
Urban	95	0.15	3.3
Row and Close-grown Crops	20	0.03	0.7
Grassland	218	0.34	7.6
Forest & Woodland	2412	3.77	84.2
Wetlands and Open Water	111	0.17	3.9
Barren	7	0.01	0.2
Totals:	**2864**	**4.47**	**100.0**

[6] Although King Arthur's Dam, constructed in 1980, is easily identified on aerial photographs, it has yet to be portrayed on the USGS topographic maps and GIS layers, and was manually added to Figure 1.

Figure 2. Map of Land Use in the Upper Pond Creek (WBID 2128) Watershed



2.4 Soils and Geology

The Washington County Soil Survey describes the area and soils as follows:

> Washington County is part of the Interior Highlands Division, Ozark Plateau Province, Springfield-Salem plateaus section. It has a variety of landforms, surface features, geologic formations, structural complexities, and mineralized trends.
>
> Streams typically flow to the north, away from the St. Francois Mountains and the Ozark Dome. Tributaries of the Big River drain to the east.
>
> The Potosi Formation, where barite was mined, is located in the southwestern and eastern parts of the county. The major soils are Gravois on the ridges, Goss on the side slopes, and Tiff in mined areas (USDA NRCS 2005).
>
> The Potosi Formation is dominated by massive beds of dolostone with an abundance of quartz druse also called mineral blossom. The Goss, Moko, and Sonsac soils dominate these areas (USDA NRCS 2006).

A map illustrating the soil types in the Pond Creek watershed can be found in Figure 3a. The headwaters of Pond Creek incise the Tiff soil series, which consists of very deep (over 60 inches), well-drained, moderately permeable soils that formed clayey residuum[7] on uplands. These soils are on nearly level to moderately steep areas that have been truncated by mining operations with slopes ranging from 1 to 20 percent. The soil's taxonomic class is clayey-skeletal, kaolinitic, mesic Rhodic Paleudalfs. Typical pedon[8] is tiff gravelly clay - on a convex escarpment of 13 percent slope in a mined area at an elevation of 710 feet (USDA NRCS 2005).

The relationship of the Tiff soil series (labeled "gravelly-clayey residuum") and the overlying Gravois-Goss complex can be found in Figure 3b. Where exposed, the Tiff soil series and the barite-rich clay materials found in barite tailings areas are similar in appearance and composition. For this reason it is often difficult to distinguish between historic abandoned barite mine areas and more recently disturbed Tiff soils. Therefore, for the purposes of the Pond Creek TMDL the materials classified as "mine tailings" and "tiff gravelly clay" will be considered similar materials.

Barite, or barium sulfate, also known as "tiff," is a mineral used in well-drilling mud, chemical manufacture, fillers and extenders, face powders, chocolate coatings, glass making, golf and bowling ball cores, in paint and with X-rays. Barite is only sparingly soluble and being a compound formed by a metal and an anion (SO_4^-) of a strong acid (H_2SO_4), it has no effect on pH when it dissolves. The Washington County barite deposits are of the residual type (lumps of barite enclosed in clay). The barite-rich clays accumulated from the solution and weathering of impure carbonate rocks. Such residuum is typically stained red or brown by insoluble iron oxide. Potentially acid-producing sulfide minerals are not associated with these barite ores. Acid-producing hydrolysis of pyritic iron, with its production of orange or red flocculants, is probably not a factor here. Instead, the red color is due to fine red-stained clay (Brian Hicks, R.G., formerly with the department's Land Reclamation Program, e-mail communication, April 2, 2003). Water samples taken from Pond Creek by department staff in 2008 and 2009 revealed acceptable pH measurements of 8.0 to 8.4, with no indication of acidity (Appendix A-2).

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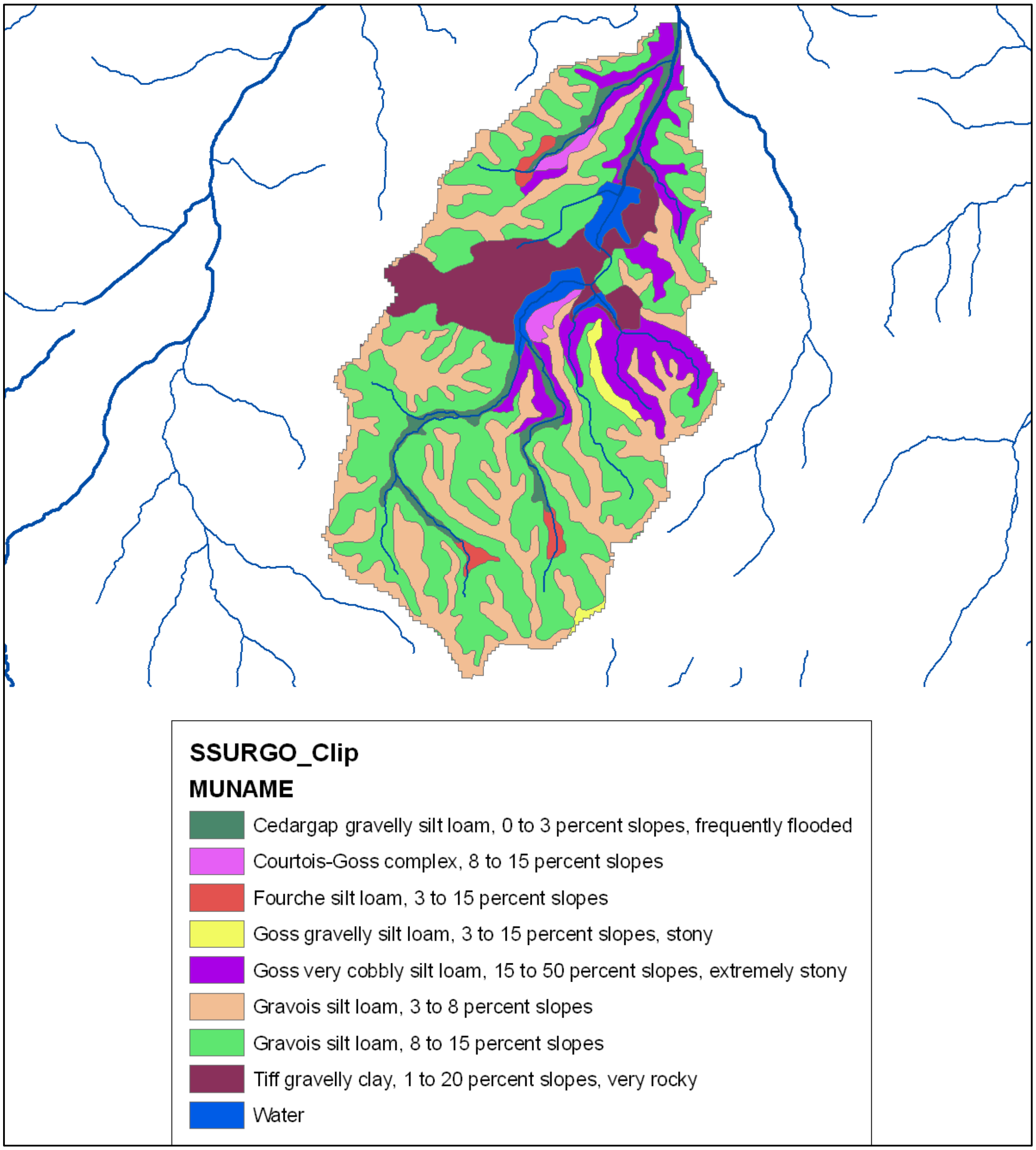
[7] Parent material is the unconsolidated mass in which a soil forms. The type of parent material from which the Tiff soil series formed is residuum – material weathered from bedrock.

[8] A pedon is a three-dimensional body of soil large enough to study its horizons. It is about one meter square by 1.5 to 2 meters deep (Kohnke and Franzmeier 1995).

Figure 3a. Map of Soils in the Upper Pond Creek (WBID 2128) Watershed (NRCS 2007

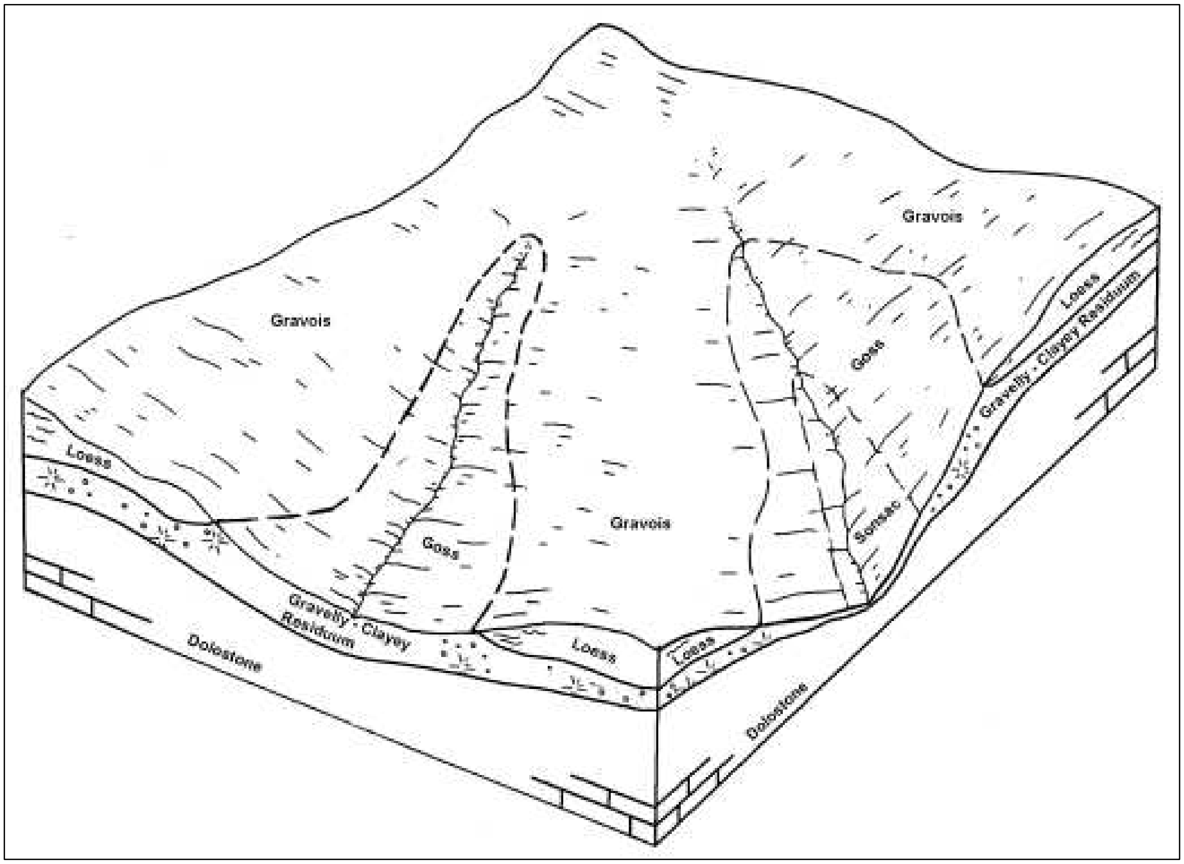


2.5 Barite Mining

Because a barite tailings dam was first identified as the source of Pond Creek's impairment, this section will catalog the history of barite mining and the associated tailings dams in the watershed.

The first step in processing barite was to wash the mined material to separate the barite ore from the red clay and gravel found with it. Barite was hauled by trucks to barite "washers" where high pressure hoses and jigging tables were used to separate the barite from the red clays and any host rock. The used wash water (slurry) flowed into a pond where the red clays and rock settled out, and water from these ponds was pumped back to be used in the washers.

Figure 3b. Typical pattern of soils and parent material in the Goss-Gravois association (Figure 10 from USDA NRCS 2005).



Old barite mining dams, such as those in the Pond Creek watershed, were built prior to enactment of current safety law administered by the department's Dam and Reservoir Safety Program. These dams are registered with permit numbers beginning with the letter "R" to indicate that status, as opposed to dams registered under current safety laws, which are registered with permit numbers beginning with "S." The old barite dams are handled differently by the Dam and Reservoir Safety Program than a modern dam, and they are given an "industrial registration permit" rather than a regular permit. The barite mining companies were allowed to keep adding coarse rock, which had been separated from the ore, to the top of the dams as a means of building up dam height to increase the size of these settling ponds. The inside slopes of these additions were covered with clay to ensure a water-tight seal (Donald Smith, Cimbar Performance Minerals, personal communication, April 6, 2010). This was allowed without the companies being required to have department staff approve the additions on-site every time. Instead, the department would inspect the new additions during their next scheduled inspection. Some of these dams were added to in this manner over a period of 10 or more years.

Due to the nature of the material used to build these dams, the dams themselves always seep water. The seeping water will often appear oily-looking, as it does for all seeping dams due to bacteria metabolism of organics in clay. As long as no sediment is moving through the dam (i.e., the seep water is clear), Dam and Reservoir Safety Program staff are not concerned. If sediment is seen passing through the dam, department staff will require the permittee to construct some

sort of filter over the seep. For example, an embankment drain might be required, which is a layer of geo-fabric covered with graded material (e.g., limestone) in layers, ending with a pipe drain for future monitoring of water clarity (Glenn Lloyd, the department's Dam and Reservoir Safety Program, personal communications, Dec. 5 and 10, 2008). As expected, King Arthur's Dam seeps. The largest seep runs down the left side of the downstream face of the dam and has existed long enough to support hydrophilic vegetation such as scouring rush, sycamore trees, and cattails, especially at the dam toe.

Although other dams regulated by the Dam and Reservoir Safety Program are required to have both a primary spillway (e.g., a hardened pipe) and a secondary spillway (which does not have to be hardened), barite tailings dams are not required to have both. Program staff feel that it is acceptable for a barite tailings dam to only have an open channel spillway as long as active erosion is minimal and not jeopardizing the dam's structural integrity. Often, portions or all of the downstream face of these dams remain barren even after decades, not necessarily because they are somehow toxic, but because they lack the soil, nutrients and water retention needed to support plant life in the upper layers (Pat Mulvany, the department's Division of Geology and Land Survey, e-mail communication, Nov. 3, 2009). Some of the lack of vegetation can also be attributed to the requirement to keep all brush and woody growth off the dams to ensure continued structural integrity.

When mining was active, water from a tailings pond was reused at the barite washer. Over time large deposits of red clays and gravels developed behind these dams, often as a deep layer the consistency of thick pudding (Glenn Lloyd, the department's Dam and Reservoir Safety Program, personal communications, Dec. 5, 2008). If wash water went over the spillway before the suspended clay had time to settle out, overflows could contain suspended clay material that would subsequently be deposited in the bottom of receiving streams. In addition, if the open channel spillways experienced erosion, clays and gravels would be deposited downstream from that source as well (John Ford, the department's Water Protection Program, e-mail communication, April 2, 2003). If the lake impounded by King Arthur's Dam was actually ever used for barite washing, both unsettled wash water and spillway erosion could have been contributing the problem sediment that lead to the department first adding Pond Creek (as "Tributary to Pond Creek") to the 1998 303(d) List.

Mining in Washington County occurred for decades before the existence of environmental regulations. Before modern mechanization came to the local mining world, it was common in Washington County for people to hand-mine lead on their family property. Barite was thrown to the side along with other non-lead "waste." Barite mining in the vicinity became a very competitive business starting in the 1920s. Mining was done by hand, as was the washing of the barite from its host rock and soil, until the first mechanical washer, made mostly of wood, was installed in 1925 at another mining area near Cadet, north of King Arthur's Dam. Several of the bigger, yet still primitive (by modern standards), operations went out of business when environmental regulations came into existence (Donald Smith, Cimbar Performance Minerals, personal communication, Nov. 4, 2009 and April 6, 2010).

The Blue Heron Dam was first constructed in 1946 to support the washing of mined barite. The dam continued to be built higher over time and the surface acreage of the tailings impoundment increased through 1969. A survey of current and archived department databases and hard copy

records did not produce further information on this dam aside from those records associated with the department's Dam and Reservoir Safety Program, as discussed in Section 5.1.1.

King Arthur's Dam was completed in 1980 by IMCO Services (then a division of Halliburton Energy Services) as an Apex Tailings Impoundment. Although not confirmed, it is assumed that the impoundment was, or was meant to be, used as a wash water supply and settling basin to support IMCO's barite mining operation. More information on King Arthur's Dam may be found in Section 5.1.2. Once King Arthur's Dam was completed, any discharged water from Blue Heron Lake, and all of its impounded tributaries, was directed into the lake impounded by King Arthur's Dam, rather than directly into Pond Creek.

No evidence of substantial, active mining activities were observed by department staff in Pond Creek, or from area roads, during field visits from the mid-1980s through Pond Creek's first appearance on the 1998 303(d) List, nor since. However, small operations would not necessarily have produced the obvious evidence and activity associated with larger mining operations and may not have been noticed (John Ford, the department's Water Protection Program, personal communication, May 5, 2010). Specific information on when barite mining ceased in the Pond Creek watershed is not available. However, as of the early 2000s, the department's Land Reclamation Program no longer had any active barite mines under permit (Bill Zeaman, Land Reclamation Program, personal communication, Nov. 3, 2009).

At the time this TMDL was developed, the properties associated with these two dams, and their impounded lakes, belonged to individual private landowners and homes had been built in the area. Figure 4 illustrates King Arthur's Dam and part of the lake in Aug. 2008.

3. APPLICABLE WATER QUALITY STANDARDS AND WATER QUALITY TARGETS

The purpose of developing a TMDL is to identify the pollutant loading that a water body can assimilate and still achieve water quality standards. Water quality standards are therefore central to the TMDL development process. Under the federal Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S. Code Title 33, Chapter 26, Subchapter III (U.S. Code, 2009)). Water quality standards consist of three components: designated beneficial uses, water quality criteria to protect those uses, and antidegradation rules.

3.1 Designated Beneficial Uses

Pond Creek (WBID 2128) has the following beneficial uses:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation - Category B

Use that is impaired:

- Protection of Warm Water Aquatic Life

The stream classifications and designated uses may be found in the Missouri Water Quality Standards at 10 CSR 20-7.031(1)(C) and (F) and Table H (MoDNR 2009).

Figure 4. King Arthur's Dam, looking east (See hash marks drawn along dam crest). The current landowner's private residence is off the photo to the right of the boat dock (Photo taken Aug. 2008)**.**

3.2 Antidegradation Rules

Missouri's Water Quality Standards include the U. S. Environmental Protection Agency (EPA) "three-tiered" approach to antidegradation, which may be found at 10 CSR 20-7.031(2).

Tier 1 – Protects existing uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after Nov. 28, 1975, the date of EPA's first Water Quality Standards Regulation.

Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economic and social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses.

Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges and waters of exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

Waters in which a pollutant is at, near, or exceeds the water quality criteria are considered in Tier 1 status for that pollutant. Because Pond Creek is listed as impaired, it is exceeding the water quality standards for sediment for sediment and metals in the sediment. Therefore, the antidegradation goal for Pond Creek is to restore the stream's inorganic sediment and metals levels to the water quality standards.

3.3 Water Quality Criteria that Apply

3.3.1 Inorganic Sediment

Although Pond Creek is listed as impaired by inorganic sediment, Missouri has no numeric criteria for inorganic sediment. As such, the impairment is based on exceedence of the general, or narrative, criteria contained in Missouri's water quality rules at 10 CSR 20-7.031(3)(A), (C) and (G)(MoDNR 2009):

(A) Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly, or harmful bottom deposits or prevent full maintenance of beneficial uses.
(C) Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor, or prevent full maintenance of beneficial uses.
(G) Waters shall be free from physical, chemical, or hydrologic changes that would impair the natural biological community.

And from 10 CSR 20-7.031(4)(H):

(H) Solids. Water contaminants shall not cause or contribute to solids in excess of a level that will interfere with beneficial uses. The stream or lake bottom shall be free of materials which will adversely alter the composition of the benthos, interfere with the spawning of fish or development of their eggs or adversely change the physical or chemical nature of the bottom (MoDNR 2009).

When water quality criteria are expressed as a narrative, a measurable indicator of a pollutant may be selected to express the narrative as a numeric value. There are many quantitative indicators of sediment, such as total suspended solids (TSS), turbidity, and bedload sediment, which are appropriate to describe sediment in rivers and streams (USEPA 2006b). A concentration of total suspended solids was selected to represent the numeric target for this TMDL because it enables the use of the highest quality available data and is included in permit requirements and monitoring data.

3.3.2 Metals

The biological impairment of Pond Creek can also be attributed to elevated metals concentrations associated with fine sediment generated by the barite mining activities within the watershed. Toxic effects of metals in the sediment on the biological community in Pond Creek are a violation of both general and specific Missouri water quality criteria.

General criteria found at 10 CSR 20-7.031(D) states:

(D) Waters shall be free from substances or conditions in sufficient amounts to result in toxicity to human, animal, or aquatic life (MoDNR 2009).

Specific criteria for toxic substances found at 10 CSR 20-7.031(4)(B)1 states:

(B)1. Water contaminants shall not cause the criteria in Tables A and B to be exceeded. Concentrations of these substances in bottom sediments or waters shall not harm benthic organisms and shall not accumulate through the food chain in harmful concentrations, nor shall state and federal maximum fish tissue levels for fish consumption be exceeded (MoDNR 2009).

Current cadmium, lead and zinc criteria for the protection of aquatic life use are expressed in dissolved form in units of micrograms per liter, or µg/L. These criteria are hardness dependent and calculated from the formulas shown below from Table A of 10 CSR 20-7.031:

Dissolved Cadmium

$$\text{Acute} = e^{(1.0166 * \ln(\text{Hardness}) - 3.062490)} * (1.136672 - (\ln(\text{Hardness}) * 0.041838)) = \mu g/L$$

$$\text{Chronic} = e^{(0.7409 * \ln(\text{Hardness}) - 4.719948)} * (1.101672 - (\ln(\text{Hardness}) * 0.041838)) = \mu g/L$$

Dissolved Lead

$$\text{Acute} = e^{(1.273 * \ln(\text{Hardness}) - 1.460448)} * (1.46203 - (\ln(\text{Hardness}) * 0.145712)) = \mu g/L$$

$$\text{Chronic} = e^{(1.273 * \ln(\text{Hardness}) - 4.704797)} * (1.46203 - (\ln(\text{Hardness}) * 0.145712)) = \mu g/L$$

Dissolved Zinc

$$\text{Acute} = e^{(0.8473 * \ln(\text{Hardness}) + 0.884211)} * 0.978 = \mu g/L$$

$$\text{Chronic} = e^{(0.8473 * \ln(\text{Hardness}) + 0.785271)} * 0.986 = \mu g/L$$

where “e” is the base of the natural logarithm (~2.718) and “ln” is the natural logarithm.

Concentrations of fine sediment, metals in the sediment, and dissolved metals will also be used as TMDL targets for the Pond Creek TMDL.

3.4 Water Quality Targets

For this TMDL, sediment targets were derived using generalized information from the ecological drainage unit (EDU) in which Pond Creek is contained (See Section 2.1 for a definition of an EDU). In this case, the Ozark/Meramec Ecological Drainage Unit (No. 25) was used.

Targets for metals in sediment were developed using the Equilibrium Partitioning Methodology as described in Section 4.3.

The 25th percentile hardness value must be used to calculate hardness dependent dissolved metals criteria per 10 CSR 20-7.031(1)(Y) that states:

(Y) Water hardness—The total concentration of calcium and magnesium ions expressed as calcium carbonate. For purposes of this rule, hardness will be determined by the lower quartile (twenty-fifth percentile) value of a representative number of samples from the water body in question or from a similar water body at the appropriate stream flow conditions.

Using available hardness data with this formula results in the 25th percentile of hardness in the Pond Creek watershed being 160 mg/L. Therefore, the corresponding dissolved chronic and acute cadmium targets for Pond Creek are 0.3 and 7.5 µg/L respectively. Likewise, the dissolved chronic and acute lead targets are 4.2 and 107 µg/L respectively, and corresponding zinc chronic and acute targets are 159 and 174 µg/L. The water quality targets for cadmium, lead and zinc

will be based on the chronic criteria to ensure aquatic life will be protected from acute and chronic toxicity. Therefore, targets for Pond Creek are 0.3 µg/L for cadmium, 4.2 µg/L for lead and 159 µg/L for zinc.

4. WATER QUALITY PROBLEM IDENTIFICATION AND CURRENT CONDITIONS

As per Missouri water quality rules, all waters of the state must provide a suitable condition for aquatic life. The conditions include both the physical habitat and the quality of the water. TMDLs are not written to address habitat, but are written to correct water quality conditions. The water quality condition addressed in this TMDL is sedimentation.

The stream was placed on the 1998 Missouri 303(d) List primarily based on the department's multiple observations of instream conditions violating narrative water quality criteria in the form of sediments being deposited into the stream. At the time, no sediment data existed to directly document sediment impacts to the stream.

4.1 Water Quality Issues and Mining Activities

Inorganic sediment is composed of mineral particles such as clay, silt, sand, assorted-sized rocks and other non-organic materials. These particles enter the stream via erosion of soils or other materials within the watershed. The deposited red clays constitute the inorganic sediment that impair Pond Creek. When these solids enter a stream, they settle onto the bottom, smothering natural substrates (and interstitial spaces associated with that habitat), aquatic invertebrates and fish eggs (John Ford, the department's Water Protection Program, e-mail communication, April 2, 2003). Dissolved metals, whether in the water column or in the sediment pores[9], pose a significant risk to aquatic life (Hansen *et al.* 2005, Besser *et al.* 2009).

The effects of mining on streams in the area was documented in the early 1960s in the Missouri Water Pollution Board's first published report on water quality, *Water Quality of Big, Bourbeuse and Meramec River Basins*, specifically in Part V, "The Benthos of Meramec River Basin as Related to Water Quality." The pools in Mill Creek near Cadet were reported to be "choked with red clay from barite washing" operations upstream (Kuester 1964). As discussed in Section 2.5, mining in the upper Pond Creek watershed likely stopped at least 20 years ago.

4.2 Water Quality Data

4.2.1 Biological Data

In October 2002, the department conducted a qualitative examination of the aquatic invertebrate benthic community of Pond Creek (See Appendix A-1, Site 2), two other streams with an inactive barite tailings pond, and one without a barite tailings pond, which was used as a control. The results of this survey are summarized in Table 2. Using this evaluation methodology, a stream's biological community is considered healthy if the number of EPT taxa[10] in the stream are equal to or greater than those found in one quarter of the reference streams in its area (i.e., high quality streams in the ecological drainage unit, or EDU). Note that Rubeneau Creek, although considered the "control" stream in this particular study, is not a reference stream. In this case, the number of EPT taxa in the 25th percentile in the fall in reference streams in the area (the Meramec basin) is eight. However, the reference streams are larger in size than the four

[9] Pore water is the water that exists in the interstitial spaces between particles (Hansen *et al.* 2005).
[10] "EPT" taxa are those three taxonomic Orders of aquatic insects (See Table 2) most intolerant of poor water quality.

streams in Table 2, and, all other things being equal, would be expected to have more taxa. In the 2002 study, Pond Creek had the highest number of EPT taxa and the highest number of total taxa of the streams studied and may have represented a typical number for an unimpaired stream of this size in this area of the state. Regardless, since the general water quality criteria were not being met (i.e., excess sediment), Pond Creek continued to be included on the 2002 303(d) List of impaired waters.

Table 2. Summary of qualitative aquatic invertebrate sampling of four streams in eastern Washington County, Oct. 2002 (MoDNR 2002a).

Stream	*Total Number of Taxa*	*Total Number of EPT* Taxa*
Tributary to Pond Creek – inactive tailings pond	23	7
Tributary to Mineral Fork – inactive tailings pond	20	6
Rubeneau Creek – control	16	6
Shibboleth Branch – inactive tailings pond	17	5

* EPT= Ephemeroptera, Plecoptera and Trichoptera (Mayflies, Stoneflies and Caddisflies)

Since the first listing of Pond Creek on the 303(d) List, the department has developed a sediment protocol to determine if sediment is actually the pollutant of concern for listed streams. The first step of this protocol is a biological assessment to determine if the stream's biological community is showing signs of impairment.

The department's Environmental Services Program conducted a biological assessment and fine sediment study on Pond Creek in the fall of 2008 and spring of 2009. The final report was published in March 2010 (MoDNR 2010b). The study included two sites on Pond Creek and covered both classified segments (WBIDs 2128 and 2127). As illustrated in Appendix A-1 and described in Appendix A-2, Site #1 was on the furthest downstream segment, WBID 2127, near the mouth of Pond Creek. Site #2 was on WBID 2128, the upstream, impaired segment on which this TMDL is written, just downstream of the Pond Creek Road bridge.

The department tested five stream sites within the Ozark/Meramec Ecological Drainage Unit (EDU) as reference streams ("EDU" is defined in Section 2.1). The five sampling sites are described in Table 4. Of these five streams, two, Shoal Creek and the West Fork of Huzzah Creek, were found to be fully supporting of aquatic life (i.e., meeting water quality standards), as measured by macroinvertebrate counts. As a result, data from these two streams serve as control sites for this TMDL.

Table 3. Sampling sites on Pond Creek and control streams.

Stream	*Site*	*Class*	*Lat/Long*	*Description/County*
Pond Cr. @ Pond Creek Rd (#2)	2128/0.8	C	37.9542/-90.6807	Pond Cr. @ NESE Sec.3,T37N,R3E
Pond Creek near mouth (#1)	2127/0.1	P	37.9779/-90.6675	Pond Cr. 0.1 mi. ab. conf. w/Mill Cr.& Hwy.47,NWNE Sec.35,T38N,R3E
West Fork Huzzah Creek	1923/0.1	C	37.6346/ -91.2592	NWNW S22, T34N, R3W/ Dent
Shoal Creek	1934/6.3	P	37.8202/ -91.1372	NESW S22, T36N, R2W/ Crawford

Dominant macroinvertebrate families were cataloged, and the macroinvertebrate community was examined using Macroinvertebrate Stream Condition Index (MSCI) scores based on individual metric scores for each sampling station for the fall and spring seasons.

A Macroinvertebrate Stream Condition Index (MSCI) is a qualitative rank measurement of a stream's aquatic biological integrity (Rabeni *et al.* 1997). The MSCI was further refined for reference streams within each EDU in *Biological Criteria for Perennial/ Wadeable Streams* (BIOREF; MoDNR 2002b), where comparisons are made between test streams and a BIOREF scoring range generated from data collected from wadeable/perennial reference streams. A sampling site's (i.e., station's) MSCI score ultimately identifies the ability of the stream to support the beneficial use for the protection of warm water aquatic life (AQL).

The MSCI score is a compilation of rank scores that were assigned to individual biological criteria metrics as a measure of biological integrity. Four primary biological criteria metrics were compared to respective BIOREF scoring ranges and were used to calculate the MSCI per station: 1) Taxa Richness (TR); 2) Ephemeroptera/Plecoptera/ Trichoptera Taxa (EPTT); 3) Biotic Index (BI); and 4) Shannon Diversity Index (SDI). Metric scores are compared to the BIOREF scoring range (BIOREF Scoring Table) and rank scores (5, 3, 1) are assigned to each metric. Rank scores are compiled and the MSCI was completed for each station. The MSCI scores are interpreted as follows: 20-16 = full support of AQL; 14-10 = partial support of AQL; and 8-4 = non-support of AQL. Further information on this biometric scoring system can be found in Sarver *et al.* 2002.

Because Pond Creek was generally smaller than the typical wadeable/perennial reference stream used to create the BIOREF criteria, the final scores presented in this TMDL represent metric evaluations generated for each season using only the similar size control streams. Comparing Pond Creek to similar size control streams seemed more appropriate since there were concerns that the impairment assessment of upper Pond Creek could have been due to unfair comparisons to the larger BIOREF streams. It was possible that stream size could have potentially affected the BIOREF MSCI scores in past analyses, and ultimately, the categorization of the creek. The small control streams had fewer TR, lower BI, lower SDI, and seasonally lower EPTT than the larger BIOREF streams used in past comparisons, which confirmed the suspected distinct difference based on size and validated the decision to use only comparisons to similar size streams.

MSCI scores were compared among sampling stations and grouped by season. Biological Criteria Metric Scores, Biological Support Category, and MSCI Scores are presented in Tables 4 and 5.

Table 4. Control Criteria Metric scores, Biological Support Category, and Macroinvertebrate Stream Condition Index (MSCI) scores using similar size stream criteria, Fall 2008.

Stream and Station No.	*Sample No.*	*TR*	*EPTT*	*BI*	*SDI*	*MSCI*	*Support*
Pond Creek #2	0804107	78	**18**	**6.7**	**2.89**	**14**	P
Pond Creek #1	0804105	104	31	**5.3**	3.75	18	F
Shoal Creek	0804110	82	22	**5.9**	3.11	18	F
W. Fk. Huzzah Cr.	0804116	82	24	5.1	3.56	20	F
Control Score=5	--	>75	>21	≤5.1	>2.97	20-16	**F**ull
Control Score=3	--	75-37	21-11	5.1-7.5	2.97-1.49	14-10	**P**artial
Control Score=1	--	<37	<11	>7.5	<1.49	8-4	**N**on

Control criteria MSCI Scoring Table (in light gray) developed from Control streams (n=6); TR=taxa richness; EPTT=Ephemeroptera, Plecoptera, Trichoptera Taxa; BI=Biotic Index; SDI=Shannon Diversity Index; **Bold**= not attaining optimum Control criteria score

Table 5. Control Criteria Metric scores, Biological Support Category, and Macroinvertebrate Stream Condition Index (MSCI) scores using similar size stream criteria, Spring 2009.

Stream and Station No.	*Sample No.*	*TR*	*EPTT*	*BI*	*SDI*	*MSCI*	*Support*
Pond Creek #2	0930003	90	**24**	**6.1**	3.16	16	F
Pond Creek #1	0930002	90	**26**	**5.5**	3.69	16	F
Shoal Creek	0930008	99	**23**	**5.6**	3.77	16	F
W. Fk. Huzzah Cr.	0930016	96	29	4.3	3.36	18	F
Control Score=5	--	>81	>26	<4.5	>3.00	20-16	**F**ull
Control Score=3	--	81-41	26-13	4.5-7.3	3.00-1.50	14-10	**P**artial
Control Score=1	--	<41	<13	>7.3	<1.50	8-4	**N**on

Control criteria MSCI Scoring Table (in light gray) developed from Control streams (n=6); TR=taxa richness; EPTT=Ephemeroptera, Plecoptera, Trichoptera Taxa; BI=Biotic Index; SDI=Shannon Diversity Index; **Bold**= not attaining optimum Control criteria score

Pond Creek Site #1, on the lower of the two segments, was found to meet water quality standards (i.e., “fully support”) in both the spring and fall, suggesting that the impairment did not extend downstream. Although macroinvertebrate scores for Pond Creek Site #2 (the impaired segment) met water quality standards in the spring of 2009, they failed to do so in the fall of 2008, even when the scores were generated through comparisons to similar size streams. The list of individual Ephemeroptera (mayflies) taxa found at Site #2 in the fall of 2008 (Sept. 24; MoDNR 2010b) included both the burrowing mayfly, Hexagenia, a taxon known to be tolerant of fine sediment, and *Isonychia bicolor*, a mayfly taxon that is intolerant to fine sediment.

It is important to note that Pond Creek Site #2 (on the impaired segment) was observed to be a small, predominantly bedrock-dominant stream segment with a shallow coating of fine sediment (See Figure 5). It was proposed in the department study that bedrock does not provide ideal habitat for macroinvertebrates and may have contributed to the appearance of an impairment.

4.2.2 Chemical and Physical Data

As mentioned in Section 4.2.1, the department’s Environmental Services Program (ESP) conducted a biological assessment and fine sediment study on Pond Creek in the fall of 2008 and the spring of 2009 (MoDNR 2010b). Site locations and descriptions are found in Appendix A. As also mentioned in Section 4.2.1, Shoal Creek and the West Fork of Huzzah Creek were found to be fully supporting of aquatic life, and, as a result, data from these streams serve as control sites for this TMDL.

Estimates of fine sediment cover within the stream beds of Pond Creek and the control streams were made using procedures described in Appendix B. Results are illustrated in Figure 6 and the complete data set is found in Appendix B.

Pond Creek Site #2 had significantly greater ($p<0.05$) relative coverage of fine sediment than did the controls. Approximately 90 percent of the bedrock substrate at Site #2 was covered with a thin coating of fine sediment that seemed to be a reddish, clay-like material. Although the fine sediment coverage was much lower downstream at Pond Creek #1, it was still higher than the controls. The quantity of fine sediment may have altered the macroinvertebrate community in the upstream station, as observed in the MSCI score, and is considered a potential contributor to

the assessed impairment. Evidence of this influence is found in the fact, as mentioned previously, that mayfly taxa known to be tolerant of fine sediment, as well as those taxa known to be intolerant to fine sediment, were both found at Pond Creek Site #2.

Figure 5. Pond Creek (WBID 2128) near sampling Site #2, looking upstream (south) at Pond Creek Road bridge and on to King Arthur's Dam (along horizon). Note bedrock on creek bottom (Photo taken March 2009)**.**

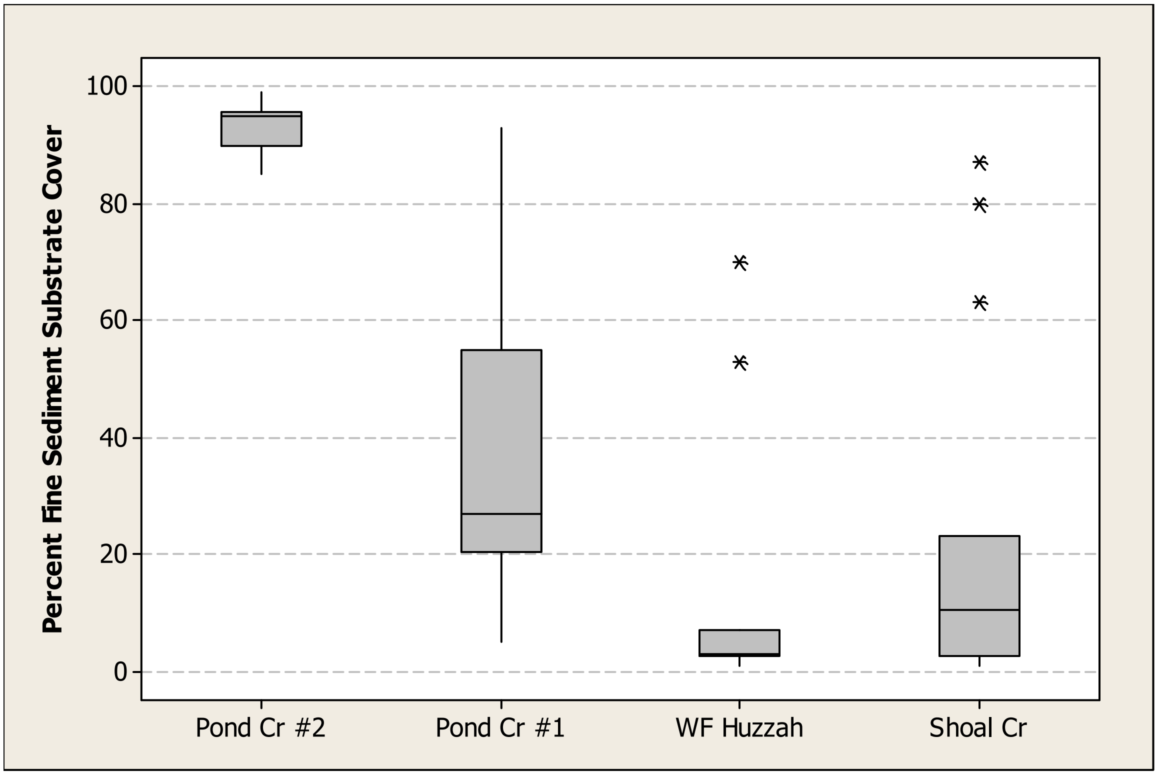
During the study, it was also observed that the tributaries of Mill Creek that had been deemed impaired, including Pond Creek, were the smallest of the streams in the study and usually had lower discharge (i.e., flow) than all other tributaries and controls. The lower observed discharge for these streams is due to the smaller area of these streams' watersheds. In the report, it was concluded that low discharge alone, or in combination with other factors, such as concentrations of metals in the pore water[11] or interstitial spaces, may also have contributed to the assessment that upper Pond Creek was impaired (MoDNR 2010b).

The department measured barium, cadmium, lead and zinc in both the water column and sediment pore water at the two Pond Creek sampling sites and in the control streams. The level of metals found in the water column did not exceed their associated water quality criteria (See Appendix A-2 and 10 CSR 20-7.030 Table A) at either Pond Creek site. However, an examination of pore water in the sediment revealed different results. Levels of cadmium, lead

[11] Pore water is the water filling the spaces between the grains of sediment.

and zinc in sediment pore water were compared to Probable Effects Concentrations (PECs) and Threshold Effect Concentrations (TECs) for these metals.

Figure 6. Boxplots of fine sediment observations in Pond Creek and control streams. (Boxes indicate 25th, 50th and 75th percentiles, lines extend to 0th and 100th percentiles, and "*" indicate outliers.)



The PEC is the level of a contaminant above which harmful effects are likely to occur and is considered an accurate basis for predicting sediment toxicity (MacDonald *et al.* 2000). The fine sediment at both sites (i.e., both WBIDs) on Pond Creek contained zinc above the associated PEC. Pore water metals concentrations within fine sediment in the control streams were not above PECs, suggesting the zinc concentrations found in Pond Creek sediment are not naturally occurring, or background levels, but are due to mining activity.

Pore water in the sediment was also analyzed relative to Threshold Effect Concentrations (TECs). The TEC is the concentration of a substance below which adverse effects are not expected to occur. As such, TECs can provide an accurate basis for predicting the absence of sediment toxicity. The results of the TEC comparisons are summarized in Table 6. For lead and zinc at both sites (i.e., both WBIDs), the results from Pond Creek indicate excursions over existing sediment quality guidelines. This is because, in the absence of promulgated numeric criteria for these metals in sediment, these concentrations exceed the consensus TECs (MacDonald *et al*. 2000).

The presence of these metals in sediment indicates mining influence from the barite operations at potentially damaging levels. However, the metals found in Pond Creek were also found in the

unimpaired tributaries of Mill Creek. The collective impact of these stressors, along with reduced flow and fine sediment, are likely causing the impairment of Pond Creek.

Table 6. Concentration of barium and heavy metals in the sediments of Pond Creek and control streams and Threshold Effect Concentrations for aquatic life (mg/kg). Note: Values in bold are those higher than the corresponding TEC.

Sample Location	*Barium*	*Cadmium*	*Lead*	*Zinc*
Pond Creek #2	1580	0.683	**46.6**	**488**
Pond Creek #1	1460	0.594	**96.8**	**525**
W Fk Huzzah Creek	21.6	0.100	10.8	9.5
Shoal Creek	15.7	0.169	15.9	45.4
Threshold Effect Concentration	--	0.99	35.8	121

4.3 Equilibrium Partitioning Methodology

Department staff prepared the TMDL with regard to potential instream concentrations of cadmium, lead and zinc in water as a surrogate for metals and sediment. This was done by developing a bedded sediment relationship between mass of sediment and mass of these metals in that sediment. Like other states, Missouri has not developed numeric criteria for bedded sediment. In order to understand the extent to which sediment toxicity could be contributing adverse effects to the aquatic environment in the Pond Creek watershed, equilibrium partitioning methodology was applied (USEPA 1999) to assess the levels of contamination from lead and cadmium. This procedure involves a number of simplifying assumptions described below. Because lead and cadmium follow well-defined partitioning behavior between pore water and sediment, measured lead and cadmium in sediment were used to estimate potential exposures in the water column based on equilibrium partitioning principles. These principles generally state that when a metal resides in sediment, it exists in equilibrium with pore water, and when physical-chemical properties are known, the partitioning behavior of the metal between the solid (sediment) and aqueous (pore water) phase can be predicted (Hansen *et al.* 2005). Pore water is important because it is known that the majority of toxicity from dissolved lead and cadmium in an aquatic environment occurs in pore water.

Following this procedure, measured lead and cadmium in sediment data were used to back-calculate pore water concentrations. Estimated pore water concentrations for the purposes of the TMDL development may then be compared to the hardness-dependent criteria promulgated by the department. Pore water concentrations are estimated by applying the following equation:

Equation 1: $[\text{metal}]_{pw,\ \mu g/L} = [\text{metal}]_{sed,\ mg/kg}/(K_{d,mL/g})*(1{,}000\ \mu g/mg)$

where $[\text{metal}]_{pw}$ is the pore water concentration, $[\text{metal}]_{sed}$ is the metal in sediment concentration and K_d is the distribution coefficient.

Based on "Partition Coefficients for Lead" from EPA (USEPA 1999), a polynomial relationship existed between the K_d value and soil pH measurements as follows:

Equation 2: $(K_{d(Pb),\ mL/g}) = 1639 - 902.4(pH) + 150.4(pH)^2$

In addition, the relationship between the K_d value and equilibrium concentrations of lead at a fixed pH can be expressed as:

Equation 3: $(K_{d(Pb),\ mL/g}) = 9{,}550\ C^{-0.335}$

where C is the equilibrium concentration of lead in µg/L.

For cadmium, an estimation of pore water concentration is derived using a similar approach:

Based on "Partition Coefficients for Cadmium" from the same publication (USEPA 1999), the relation between the K_d for cadmium and pH is best described in a linear fashion:

Equation 4: $\log_{10}[K_{d(Cd)}] = -0.54 + 0.45(\text{pH})$

EPA (USEPA 1999) provides look-up tables for the estimated range (i.e., maximum and minimum) of K_d values for lead as a function of soil pH and equilibrium concentrations, and for cadmium as a function of pH using the above equations. Equivalent relationships for zinc have not been calculated at this time.

Tables 7 and 8 present K_d values for lead and cadmium. Values for sediment pore water pH are not known. However, the Tiff soil, from which the stream sediment substantially originates, tends to range from neutral to acidic. Values for soil pH range from 4.5 to 7.3 (USDA NRCS 2005). Potential pore water concentrations for lead in Pond Creek range from 9.4 to 645.3 µg/L. In the control streams, potential pore water concentrations range from 2.2 to106 µg/L.

Water column samples that were analyzed for dissolved lead all yielded concentrations of less than 1 µg/L (See Appendix A-2), which indicates a probability of low interaction between pore water and surface water. However, elevated pore water concentrations of heavy metals represent significant risks for benthic organisms (Hansen *et al.* 2005, Besser *et al.* 2009).

Table 9 lists final chronic value (FCV) water quality criteria for the development of interstitial water benchmarks (Hansen *et al.* 2005). It should be noted that potential toxicity from metals in pore water is dependent not only on hardness and pH, but also on the mixture of sediment metals and the bioavailability of these metals as affected by the amount of organic matter within the sediment. Benchmarks for individual metals cannot be conclusively determined without consideration of the other metals present (Hansen *et al.* 2005).

Table 7a. Estimated pore water concentrations (C_{pw}) for lead at pH 4.0-6.3.

Site	Sediment Concentration (mg/Kg)	Assumed Equilibrium Conc. (µg/L)	Max Kd Value (mL/g)	Min Kd Value (mL/g)	Estimated C_{pw} based on Max Kd (µg/L)	Estimated C_{pw} based on Min Kd (µg/L)
Pond Creek #2	46.6†	10-99.9	1,850	190	25.2	245.3
		100-200	860	150	54.2	310.7
Pond Creek #1	96.8†	10-99.9	1,850	190	52.3	509.5
		100-200	860	150	112.6	645.3
W Fk Huzzah Cr	10.8	10-99.9	1,850	190	5.8	56.8
		100-200	860	150	12.6	72.0
Shoal Cr	15.9	10-99.9	1,850	190	8.6	83.7
		100-200	860	150	18.5	106.0

Note: C_{pw} = pore water concentration
† exceeds the freshwater Threshold Effect Concentration for lead of 35.8 mg/Kg

Table 7b. Estimated pore water concentrations (C_{pw}) for lead at pH 6.4-8.7.

Site	Sediment Concentration (mg/Kg)	Assumed Equilibrium Conc. (µg/L)	Max Kd Value (mL/g)	Min Kd Value (mL/g)	Estimated C_{pw} based on Max Kd (µg/L)	Estimated C_{pw} based on Min Kd (µg/L)
Pond Creek #2	46.6†	10-99.9	4,970	900	9.4	51.8
		100-200	2,300	710	20.3	65.6
Pond Creek #1	96.8†	10-99.9	4,970	900	19.5	107.6
		100-200	2,300	710	42.1	136.4
W Fk Huzzah Cr	10.8	10-99.9	4,970	900	2.2	12.0
		100-200	2,300	710	4.7	15.2
Shoal Cr	15.9	10-99.9	4,970	900	3.2	17.7
		100-200	2,300	710	6.9	22.4

Note: C_{pw} = pore water concentration
† exceeds the freshwater Threshold Effect Concentration for lead of 35.8 mg/Kg

Table 8. Estimated pore water concentrations for cadmium.

Site	Sediment Concentration (mg/Kg)	Kd (mg/g)		Estimated Pore Water Concentration (µg/L)	
		pH 4.5	pH 7.3	pH 4.5	pH 7.3
Pond Creek #2	0.683	30.549	555.904	22.4	1.2
Pond Creek #1	0.594			19.4	1.1
W Fk Huzzah Cr	0.1			3.3	0.2
Shoal Cr	0.169			5.5	0.3

Table 9. Water quality criteria final chronic value (FCV) for deriving equilibrium sediment benchmarks based on dissolved metal concentrations in interstitial water (µg/L).

Metal	Formulae	Hardness (mg CaCO3/L)		
		50	100	200
Cadmium	$[e^{(0.7409*\ln(\text{Hardness}) - 4.719948)}] * (1.101672 - (\ln(\text{Hardness})*0.041838))$	0.15	0.25	0.40
Lead	$[e^{(1.273*\ln(\text{Hardness}) - 4.704797)}] * (1.46203 - (\ln(\text{Hardness})*0.145712))$	1.2	2.5	5.3
Zinc	$[e^{(0.8473*\ln(\text{Hardness}) + 0.785271)}] * 0.986$	59.5	107.0	192.6

5. SOURCE INVENTORY AND ASSESSMENT

TMDL source assessment characterizes known, suspected and potential sources of pollutant loading to the impaired water body. Pollutant sources identified within the watershed are categorized and quantified to the extent that information is available. Sources of inorganic sediment may be point (regulated) or nonpoint (unregulated) in nature.

5.1 Point Sources

The term, point source, refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. Point sources are regulated through the federal National Pollutant Discharge Elimination System (NPDES). Both federal and Missouri clean water law prohibit the discharge of pollutants into waterways of the United States without a NPDES-type permit. In Missouri, the department's Water Protection Program Water Pollution Control Branch issues Missouri State Operating Permits to regulate discharges from point sources. In addition, the department's Water

Resources Center Dam and Reservoir Safety Program holds permit registrations on dams within their jurisdiction, including two in the Pond Creek watershed.

There are currently no Water Protection Program-permitted dischargers (facilities, stormwater outfalls or CAFOs[12]) within the Pond Creek watershed that cause or contribute inorganic sediment to the impaired segment. However, active and abandoned mine areas can be classified as point sources due to the nature of mining and milling activities, regardless if they are currently covered by a discharge permit (USEPA 1993a). Abandoned mine land areas within the watershed may therefore collectively be considered a point source even though there are no State Operating Permits on record. As a result, Blue Heron Dam and King Arthur's Dam are considered point sources for the purpose of the Pond Creek TMDL. Mine tailings historically released from Blue Heron Dam, and possibly King Arthur's Dam, are thought to have been the main contributor of inorganic sediment to the impaired water body segment. This belief is reflected in Missouri's 303(d) lists that identify a "barite tailings pond" as the source of Pond Creek's impairment. Eroded sediment from King Arthur's Dam itself may also have contributed to the impairment. As a result, this TMDL includes an assessment of the dams as to their past and current department-permitted status, as well as their condition and stability.

A search of the department's central office and regional office files did not produce a record of this area or dams ever being under permit by the Missouri State Operating Permit program. While barite mining activities have ceased and the area is not under permit by the Water Protection Program, the entire barite mining area is considered a point source of the pollutants of concern. Inclusion of the abandoned barite mining areas in the point source and wasteload allocation sections of the Pond Creek TMDL does not give these areas permission to discharge.

5.1.1 Blue Heron Dam

Blue Heron Dam (Dam Safety Identification No. MO 30478; Permit R-282) is 51 feet in height, approximately 1,100 feet long, and currently impounds a 37-acre lake in the uppermost headwaters of Pond Creek (MoDNR 2010a). The dam, located almost due east of the town of Mineral Point, was first started in 1946, to facilitate the washing of locally-mined barite. The crest of the dam continued to be built higher in elevation until 1969 (Glenn Lloyd, the department's Dam and Reservoir Safety Program, personal communication, Dec. 5, 2008).

A search of the department's records, both hard copy archives and databases, revealed almost no information on this dam and lake. There is no record of a State Operating Permit ever being issued by the department's past water programs, nor is there a record of a mining permit ever being issued by the department's Land Reclamation Program. A lack of records could possibly be explained because the lake could have stopped being used to support mining before clean water or mining law existed in Missouri.

The department's Water Resources Center Dam and Reservoir Safety Program has authority to regulate non-agricultural, non-federal dams greater than 35 feet in height, including Blue Heron Dam and King Arthur's Dam. Blue Heron Dam was inspected in April, 2003 and the owner's registration permit with the Dam and Reservoir Safety Program was renewed through May 1, 2008. The June 13, 2003 Inspection Summary read as follows:

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[12] CAFOs are concentrated animal feeding operations.

> The Blue Heron Dam is a barite tailings embankment with a principal spillway and two emergency spillways. The principal spillway consists of a 36-inch diameter corrugated metal pipe located on the right abutment [looking downstream] of the dam. Emergency spillway #1 is an open channel on the right abutment of the dam. Emergency spillway #2 consists of an open channel on the left abutment of the dam. The dam was constructed by dumping coarse waste material produced in the mining process on the embankment. This material is primarily a fine to medium gravel. The impoundment area stores fine tailings produced in the washing process. The fine tailings typically consist of very soft, high plasticity clays. There is a permanent shallow pool of water at the Blue Heron Dam.
>
> At the time of the inspection, there was no visible evidence of major stability problems or defects that would indicate the dam is unsafe. The only condition observed that requires the attention of the owner is the growth of trees and brush on the dam. This type of vegetation is undesirable on dams and should be removed. (Clay 2003a).

The Blue Heron Dam was re-inspected on April 6, 2010 and, at the time this TMDL was developed, Dam and Reservoir Safety staff were in the process of reviewing the inspection report in order to finalize their renewal recommendation.

Should Blue Heron Dam discharge, which is unlikely considering the shallow nature of the impoundment, it would do so almost immediately downstream into the reservoir impounded by King Arthur's Dam. As a result, any load from the Blue Heron Dam would be included in loads from the downstream reservoir impounded by King Arthur's Dam.

5.1.2 King Arthur's Dam

King Arthur's Dam, also known as Pond Creek Dam (Dam Safety ID No. MO 31825; Registration Permit No. R-283), is the lower of the two dams in Pond Creek's headwaters. It is approximately 77 feet in height, 1,160 feet long, and currently impounds a 33-acre lake (MoDNR 2010a). The dam is located a little more than a mile east of the town of Mineral Point. The dam embankment was built in 1980 to impound water to be used for wash water and a settling basin to support the local barite mining operation. As with the Blue Heron Dam, no records were found with the department's Water Pollution Control Branch or Land Reclamation Program. However, the Dam and Reservoir Safety Program provided documentation that IMCO Services, a division of Halliburton Energy Services, had the dam constructed to use as an "apex tailings impoundment."

The downstream face of King Arthur's Dam consists of an upper, heavily-vegetated slope below the crest (See Figures 7 and 8), followed by a flat "bench" approximately 10 to 15 feet wide (See Figures 8 and 9), followed by a second lower slope (See Figures 7 and 9) leading down to the dam's base (i.e., toe; See Figure 10). The crest (See Figure 4), and slope immediately below it, may have been built up with soil during the 2003 spillway modification, or at some point previously, as suggested by the dense vegetation in this area.

Figure 7. 2009 aerial photo illustrating Pond Creek (WBID 2128), and King Arthur's Dam and it's principal spillway, in relation to county roads.

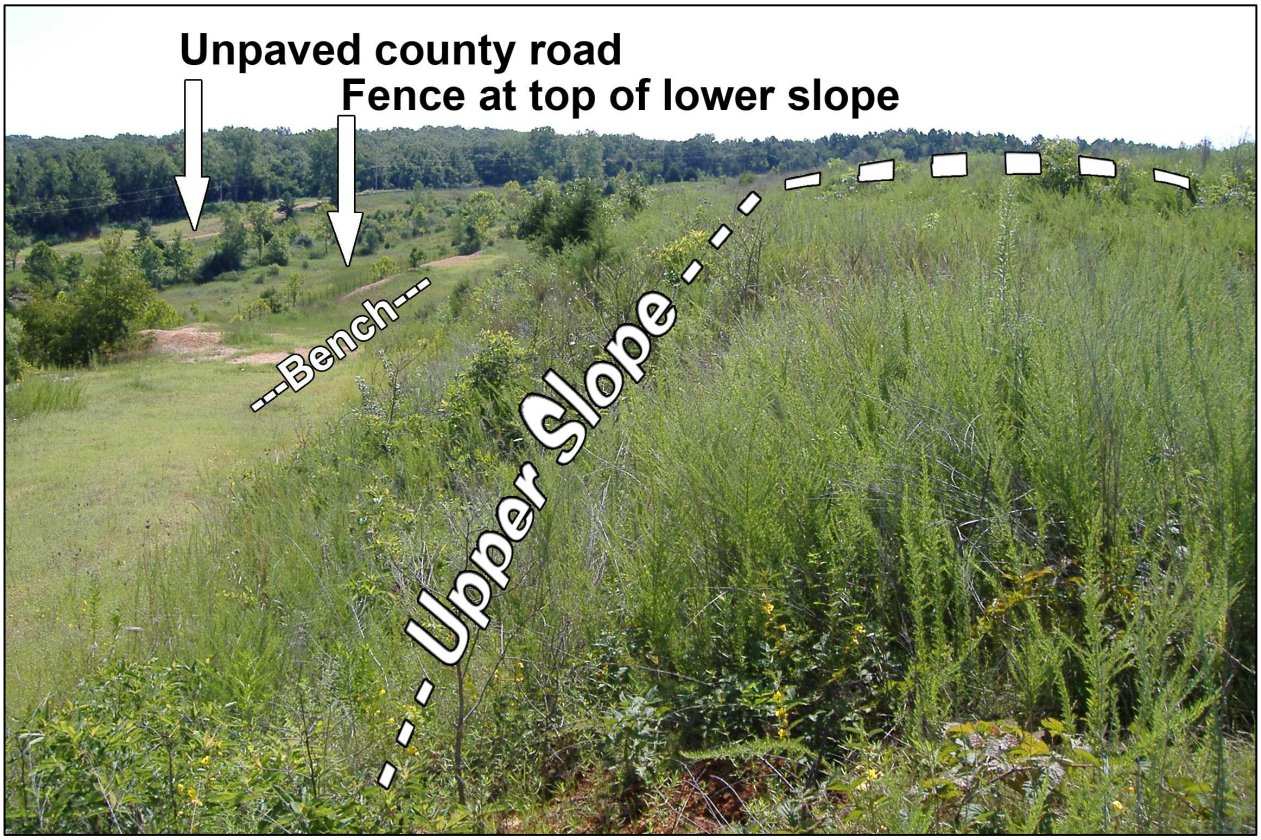
King Arthur's Dam was recertified and registered by the department's Dam and Reservoir Safety Program engineers in June 2003. The inspection summary read as follows:

> The King Arthur's Dam is a barite tailings embankment with a principal spillway. The principal spillway is an open channel on the right abutment of the dam. The dam was constructed by dumping coarse waste material produced in the mining process on the embankment. This material is primarily a fine to medium gravel. The impoundment area stores fine tailings produced in the washing process. The fine tailings typically consist of very soft, high plasticity clays. There is a permanent shallow pool of water at the King Arthur's Dam. At the time of the inspection, there was no visible evidence of major stability problems or defects that would indicate the dam is unsafe (Clay 2003b).

As a result of successful recertification, the dam was reregistered and permitted (Registration Permit No. R-283) through May 1, 2008 (Alexander 2003).

In August 2003, the current landowner was issued a construction permit (C-363) from the department's Dam and Reservoir Safety Program to construct a new principal spillway on the right abutment (See Appendix A-1) in order to raise the dam's crest and increase the lake's surface acreage. The newly constructed spillway replaced the former open channel, earthen spillway and increased the impounded water body to its current 33-acre size. In June 2009, the Missouri Attorney General filed suit against the owner of the dam for failing to provide the department with a professional engineer's certification that the construction of the new spillway

Figure 8. The heavily vegetated upper slope of the downstream face of King Arthur's Dam, looking southeast. Note relatively flat "bench" downhill from the upper slope and the fence in center of bench marking the top of the lower slope (Photo taken Aug. 2008)**.**



control structure was completed according to the approved engineering plans. The dam cannot be properly registered with the state of Missouri until the owner first provides a professional engineer's certification. The lawsuit seeks the owner's proper completion of the state's dam registration process, including an inspection by the department's Dam and Reservoir Safety Program. A lack of maintenance (e.g., tree and shrub removal (See Figures 7 and 8)) during the years since the spillway was reconstructed, might result in the dam still not meeting current inspection standards sufficient to receive a registration permit, even if the new spillway was certified (Glenn Lloyd, the department's Dam and Reservoir Safety Program, e-mail communication, Oct. 2, 2009). At the time this TMDL was developed, the lawsuit remained unresolved.

5.1.3 Additional Pollutant Sources Associated with Abandoned Mine Areas

In addition to the point sources of inorganic sediment described above, pollutant sources associated with present and historic abandoned mine areas could be causing or contributing to the impairment of Shibboleth Branch. These areas include stormwater runoff from public and private roads and driveways, home construction sites, and any areas where local soils are barren of vegetation.

The most likely possible nonpoint sources of inorganic sediment entering Pond Creek include:

- Local "Tiff" soil series
- Washington County roads

Local Tiff soil series
As discussed in Section 2.4, the headwaters of Pond Creek incise the Tiff soil series, which consists of very deep (over 60 inches), well-drained, moderately permeable soils that formed clayey residuum on uplands (See Figure 3a). These deep, red soils are ubiquitous in the area, and regardless of past mining activity, provide a continuous source of erodible material. A certain amount of sediment enters the stream naturally due to normal fluvial processes and accounts for a natural background level of inorganic sediments. The nature of this soil, and its availability for deposition into Pond Creek, is evident in the streambanks.

Washington County roads
Many of the local roads in the watershed, whose associated ditches eventually drain into Pond Creek, remain unpaved. These roads are built of local soils and materials, much of which is vulnerable to erosion. Pond Creek Road, which crosses Pond Creek just downstream (north) of King Arthur's Dam (See Figure 1), is presently blacktopped. However, the small, county road that runs along the east side of King Arthur's Dam (See Appendix A-1; Figures 7 and 8) to the current landowner's residence and to a local cemetery, is not blacktopped. This road begins at Pond Creek Road (County Road 425), just east of the Pond Creek Road bridge. It travels up a steep hill along the east side of the dam and past the landowner's home. Stormwater carrying red sediment has been observed running down and off this road and into the Pond Creek Road road ditches and into Pond Creek, both upstream and downstream of the Pond Creek Road bridge. In the process, fine particles settled out on the road surface where they are vulnerable to washing into the creek during the next precipitation event (John Ford, Water Protection Program, personal communication Oct. 29, 2009; Ross Carrabino, landowner, personal communication June 28 and 29, 2010). The steepness of the roads and the material on which they are built both contribute to vulnerability to erosion during precipitation events. Additionally, Washington County road maintenance practices on this unpaved road include addition of a mixture of rock and clay to the top of the road two to three times per year. Although the clay fraction of the material used may have been reduced in the northern part of Washington County (Todd Moyers, Washington County Commission, personal communication March 17, 2010), the current landowner of the King Arthur's Dam property reports that the added material turns to a two- to four-inch layer of mud when it rains, and the sediment-loaded stormwater routinely enters Pond Creek above and below Pond Creek Road bridge.

The road ditches can carry locally eroded soil material from the roads themselves, as well as from any local land disturbance activities, directly to Pond Creek. Regardless of whether or not the roads are surfaced, periodic county road maintenance includes opening up the ditches that run along both sides of the roads. The county does this by cutting deep into the ditch and turning the collected red clays up onto the outside top edge of the ditch (Todd Moyers, Washington County Commissioner, personal communication, March 17, 2009). This practice succeeds in temporarily opening up the ditches to facilitate handling stormwater off road surfaces and is a necessary and unavoidable road maintenance practice. Although the majority of the removed material is trucked away, it exposes freshly turned over deposits of clay soils to stormwater erosion and may serve as another source of this material.

Along with road maintenance practices, the fundamental source of the Pond Creek inorganic sediment impairment from sediment seems to be the existing, ubiquitous soil type that is not easily revegetated once disturbed, and is prone to erosion and transport.

5.1.4 Point Source Summary

The primary cause of the inorganic sediment impairment to Pond Creek was originally identified on Missouri's 303(d) lists as "a barite tailings dam." Mining in the area may have stopped over 20 years ago, and King Arthur's Dam upper slope and spillways were reworked in 2003. However, there are still bare areas associated with the lower dam slope and the areas to either side of the dam. As a result, "abandoned mine lands" are still thought to be one of the contributors to the continued impairment.

Although often without extensive vegetative cover, the barite tailings dams themselves are not necessarily, in their entirety, a source of the sediment that impairs downstream water bodies. The undisturbed coarse material on the downstream face of King Arthur's Dam has likely long had the fine clays weathered from its matrix. The barren area on the lower slope of the dam is relatively small in relation to the entire downstream dam face (See Figures 7 and 9). However, it is steep enough to make even this relatively small barren area constantly vulnerable to erosion, especially when the coarse surface material is in any way penetrated exposing the finer material beneath. If the dam's face was disturbed during the 2003 spillway modification, some amount of sediment could have eroded from the dam face, as well as the construction site, and contributed fine sediment to Pond Creek, especially upstream of the Pond Creek Road bridge.

As described in the preceding sections, abandoned barite mine areas and the ubiquitous Tiff soil series are considered the primary source of inorganic sediment loading resulting in the impairment of Pond Creek. Because historic distributions of abandoned mine areas and the Tiff soil series cannot be definitively determined, these areas are collectively lumped into the point source wasteload allocation portion of the TMDL. In addition, any activities within the watershed that may disturb, redisturb, redistribute or reuse either the barite mine tailings or Tiff soils will be considered to be part of the point source wasteload allocation for TMDL purposes.

5.2 Nonpoint Sources

Nonpoint source pollution refers to pollution coming from diffuse, non-permitted sources that typically cannot be identified as entering a water body at a single location. They include all other categories of pollution not classified as being from a point source, and are exempt from department regulation as per State rules at 10 CSR 20-6.010(1)(B)2.

Nonpoint sources of pollution that have the potential to influence water quality in streams typically include onsite wastewater treatment systems, various sources associated with runoff from urban and agricultural areas, and riparian corridor conditions. However, as described in the following sections, each of these sources is expected to have little impact on pollutant loading to the impaired segment since the inorganic sediment in question is the result of historic mining (point source) activities within the watershed.

5.2.1 Onsite Wastewater Treatment Systems

The department does not have the authority to regulate onsite wastewater treatment systems (e.g., individual home septic systems) and they are not covered through the department's NPDES permitting system. As a result, they are considered potential "nonpoint" sources of pollution. When onsite wastewater treatment systems are properly designed and maintained, they should not serve as a source of contamination to surface waters; however, onsite wastewater treatment systems do fail for a variety of reasons. When these systems fail hydraulically (surface

breakouts) or hydrogeologically (inadequate soil filtration), there can be adverse effects to surface water quality. Failing septic systems are sources of nutrients that can reach nearby streams through both surface runoff and ground water flows. However, they are not known to be large contributors of inorganic sediment to local streams. Therefore, nonpoint source loading from onsite wastewater treatment systems is insignificant and will not be addressed in this TMDL.

5.2.2 Runoff from Urban Areas

Stormwater runoff from urban areas can be a significant source of inorganic sediment. However, there are no urban centers within the Pond Creek watershed. The land use map for the Pond Creek watershed (Figure 2) does portray 3 percent of the land use being urban, but these areas are likely represented by roads, private homes and other buildings and impervious surfaces associated with the homes in the watershed. As such, true urban areas are not contributing to Pond Creek's impairment. The potential contribution of unpaved, rural roads to Pond Creek's impairment is discussed in Section 5.2.5.

5.2.3 Runoff from Agricultural Areas

Another potential source of the inorganic sediment impairment to Pond Creek is runoff from agricultural nonpoint sources. Anywhere land is exposed, soil is vulnerable to erosion and can be carried by stormwater into a stream, resulting in increased turbidity and inorganic sediment concentrations. Cropland is particularly vulnerable to erosion. However, since only 0.7 percent (20 acres) of land use in the watershed is in cropland, it is not believed to be a significant contributor to the inorganic sediment impairment of Pond Creek.

Although there are no state-permitted concentrated animal feeding operations in the watershed, the presence of lower density livestock populations must be considered as a possible source of the inorganic sediment load in Pond Creek. Livestock tend to concentrate near feeding and watering areas causing those areas to become barren of plant cover, thereby increasing the possibility of erosion during a storm event (Sutton 1990). For these reasons, overland runoff during rain events can easily carry inorganic sediment to the stream from any areas made barren by livestock related activities.

Countywide data from the National Agricultural Statistics Service (USDA NASS 2009) were combined with the size of the Pond Creek watershed to estimate that there could be up to 60 cattle in the watershed[13]. The cattle that exist are most likely located on the approximately 218 acres (7.6 percent of land use) of grassland and pastureland in the watershed. Even though a pasture may be relatively large and animal densities low, as mentioned previously, there is potential for soil erosion if animals concentrate in any one area. These areas can quickly become barren of plant cover, increasing the possibility of erosion and soil runoff during a storm event. However, the estimated density of 0.28 cattle per acre (177 cattle per square mile) in the watershed is not an excessive grazing rate based on an average recommended stocking density for Missouri of 0.25 cattle per acre (Mark Kennedy, State Grazing Land Specialist, Natural Resources Conservation Service, personal communication, Nov. 30, 2009). Grazing densities

[13] According to the National Agricultural Statistics Service, as of 2007, there were approximately 21,191 head of cattle in Washington County (NASS 2009). According to the 2005 Missouri Resource Assessment Partnership (MoRAP 2005) there are 76,568 acres of grasslands in Washington County. These two values result in a cattle density of approximately 168 cattle per square mile of grasslands. This density was then multiplied by the number of square miles of grassland in the Pond Creek watershed to estimate the number of cattle in the watershed.

Figure 9. King Arthur's Dam looking southeast at the "level bench" (on right) separating the upper dam face slope from the lower dam face slope (center). Note the fence at the top of the slope, and the unpaved county road running along the tree line east of the dam (Photo taken Aug. 2008)**.**

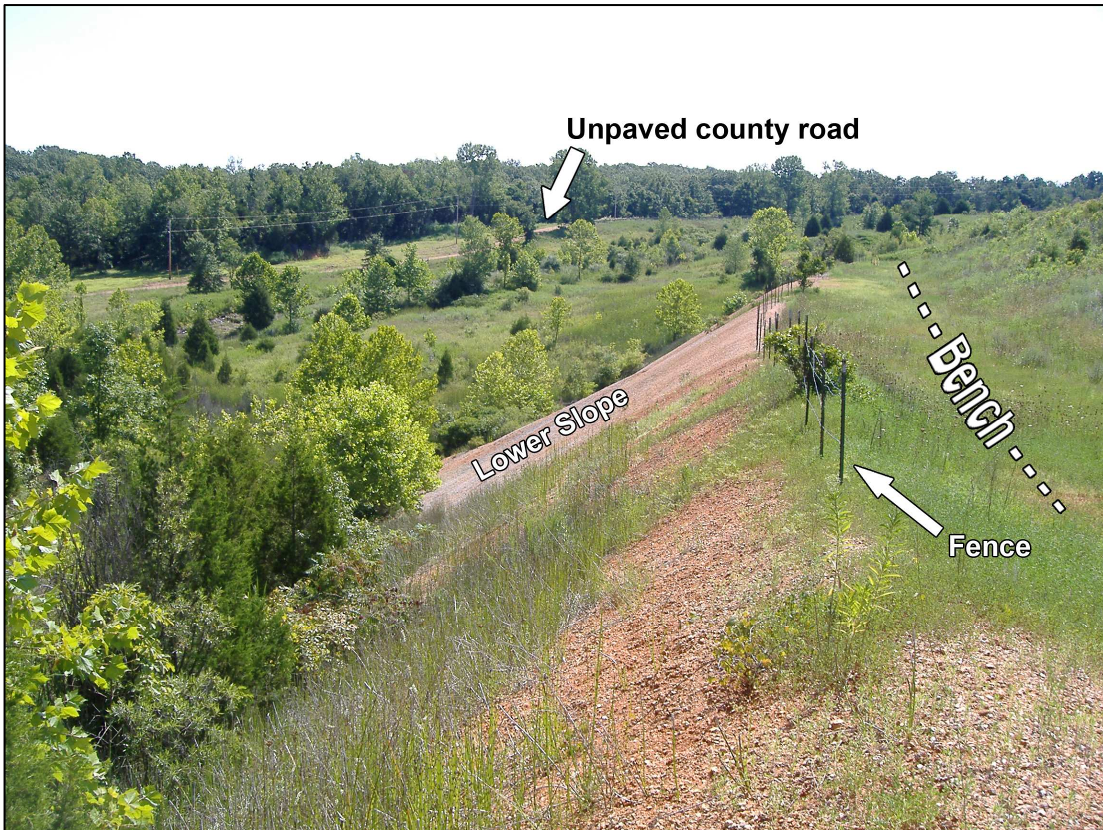
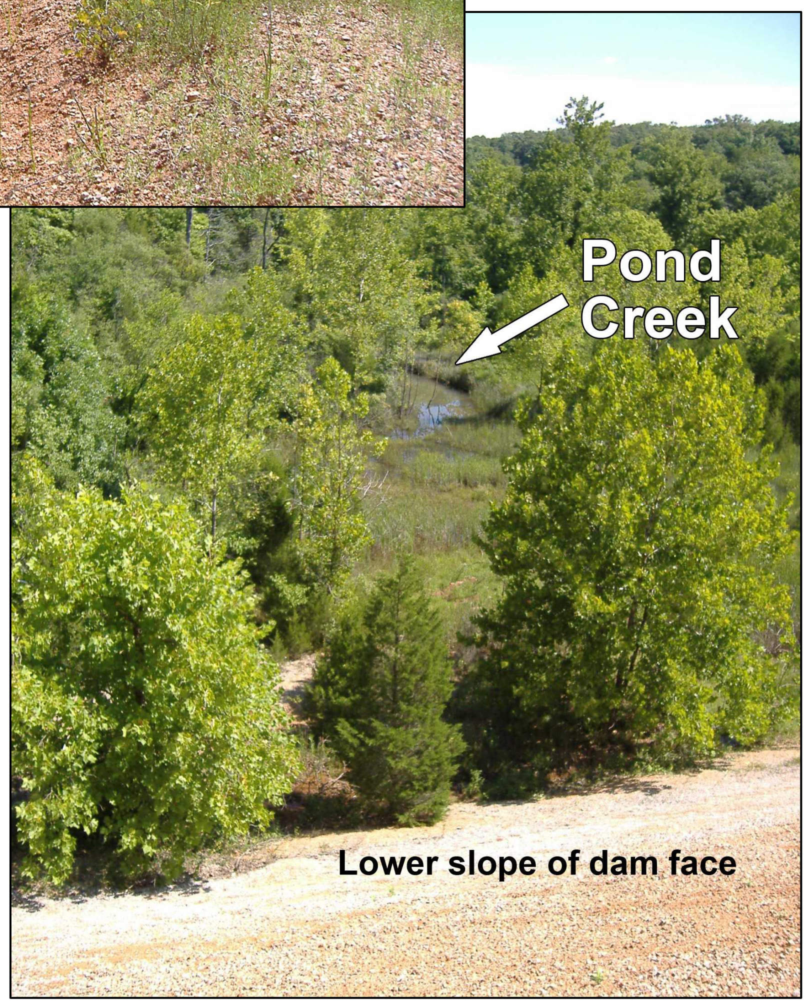


Figure 10 (to right). Looking downstream, past the toe of the dam, at Pond Creek (Photo taken by the fence at top of the lower slope (See Figure 8); Aug. 2008)**.**



recommended in Missouri by the USDA's Natural Resources Conservation Service and the department's Soil and Water Conservation Program, are those that keep soil erosion to a minimum at each site. According to the National Agricultural Statistics Service, as of 2007, there were over 1,000 horses and ponies in Washington County (USDA NASS 2009) as well, and their grazing densities also have the potential to influence inorganic sediment entering the stream. However, it is not known whether these densities are representative and limited field verification efforts seem to indicate the values may not be representative. Therefore, runoff from agricultural areas is not expected to significantly contribute to inorganic sediment loading to the impaired segment.

5.2.4 Riparian Corridor Conditions

Riparian corridor[14] conditions can also have a strong influence on whether inorganic sediment reaches a stream. Well-vegetated riparian areas are a vital functional component of stream ecosystems and are instrumental in the detention, removal and assimilation of sediment, excess nutrients and other pollutants before they reach a stream. In essence, they act as buffers. Therefore, a stream with a well-vegetated riparian corridor is better protected from the impacts of stormwater laden with sediment, nutrients and pesticides than is a stream with a poorly vegetated corridor. Wooded riparian corridors can also provide shade that reduces stream temperatures, which can increase the dissolved oxygen saturation capacity of the stream. Trees also provide a root system that helps stabilize streambanks and resist bank erosion more effectively than roots of grasses, row crops or shrubbery. As indicated in Table 10, 56 percent of the land in the upper Pond Creek riparian corridor is classified as "Forest & Woodland" (MoRAP 2005).

Table 10. Land use/land cover percentages within a 30-meter riparian corridor along Pond Creek (WBID 2128) (MoRAP 2005)**.**

Land Use/Land Cover	***Pond Creek Riparian Corridor (Percent)***
Urban	1.9
Row and Close-grown Crops	1.9
Grassland	2.8
Forest & Woodland	56.1
Wetlands and Open Water	35.4
Barren	1.9
Total:	100.0

Grassland has limited benefits in riparian corridors compared to wooded corridors and, since it may be grazed, can also be associated with livestock activities that could contribute inorganic sediment to the stream. Areas in close-grown crops have the potential to contribute large amounts of inorganic sediment to streams when best management practices for controlling erosion are not used. However, grassland and close-grown crops combined cover barely over an acre of ground (4.7 percent) in the riparian zone along Pond Creek. As such, these areas are not considered to be contributing to the impairment. Of the 24 acres in Pond Creek's riparian zone, less than 0.5 acre is in urban (likely roads) land use. The influence of roads on Pond Creek's impairment is discussed in Section 5.1, Point Sources.

[14] A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

Although 1.9 percent (less than 0.5 acre) of land in the riparian zone is reported to be barren, the only barren area in that zone, according to what is illustrated on the land use map for the entire watershed (See Figure 2), is on the lower face of King Arthur's Dam (See Figure 9). The reasons why barite tailings dams often do not support vegetation are discussed in Section 2.5, and the possibility of this contributing to Pond Creek's impairment is discussed in the Section 5.1.4, the Point Source Summary.

As indicated in Table 10, 35.4 percent of land cover in the riparian zone is represented in the "Wetland and Open Water" category. Some of these areas are evident on the map depicting land use in the entire watershed (Figure 2). Wetlands are known to intercept nutrients, pesticides and sediment before these pollutants enter streams. As mentioned previously, wooded riparian corridors, especially if the understory vegetation is thick, provide the best protection from influx of inorganic sediment. Over 91 percent of the riparian corridor along the impaired segment of Pond Creek (WBID 2128) is classified as being in woodland, wetland or open water. A lack of good riparian corridor conditions is, therefore, not likely a major contributor to the water quality problem in Pond Creek.

5.2.5 Nonpoint Sources Summary

The primary cause of the inorganic sediment impairment to Pond Creek was originally identified on Missouri's 1998 303(d) List a "barite tailings dam," more specifically, King Arthur's Dam. However, since mining and the associated barite washing likely ceased in the watershed by the early 2000s and the current landowner had the principal spillway on the dam rebuilt in 2003, abandoned mine lands (point sources) are currently thought to be the primary contributors to the continued impairment.

6. CALCULATION OF LOAD CAPACITY

Load capacity (LC) is defined as the greatest amount of a pollutant a water body can assimilate without violating Missouri Water Quality Standards. This total load is then divided among a wasteload allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). To calculate the total load (or LC), the following formula is used:

Load capacity (LC) = (design stream flow in ft^3/sec)(maximum allowable pollutant concentration in mg/L)(5.395*)
= pounds/day

*5.395 is the constant used to convert ft^3/sec times mg/L to pounds/day.

6.1 Modeling Approaches

When narrative criteria are targeted for an impaired segment, a reference approach is used. Currently, Missouri does not have a numeric criterion for inorganic sediment. Because a measurement of total suspended solids concentration is the sum of all organic and inorganic suspended solids, inorganic sediment concentration in the water column is at most equal to that of total suspended solids. Assuming the ratio of inorganic sediment to total suspended solids (TSS) is constant for a particular watershed and during a specific event, any reduction in one would parallel that of the other. Consequently, total suspended solids concentration may be used as the target for the inorganic sediment impairment.

Ecological Drainage Units (EDUs) are delineated drainage units that are described by physiographic and major riverine components. Similar size streams within an EDU are expected to contain similar aquatic communities and stream habitat conditions. Comparisons of biological, physical and chemical results between test streams and similar size reference streams within the same EDU should then be appropriate. In the case of Pond Creek, data from the Ozark/Meramec Ecological Drainage Unit (No. 25) was used.

6.2 Technical Approach and Methodology

A TMDL is defined as the total amount of pollutant that can be assimilated by a receiving water body while achieving water quality standards. A TMDL is expressed as the sum of all wasteload allocations (point source loads), load allocations (nonpoint source loads), and an appropriate margin of safety, the latter of which attempts to account for uncertainty concerning the relationship between effluent limitations, modeling and water quality. The TMDL, which is also known as the load capacity (LC) of the water body, can be expressed by the following equation:

Equation 5: $TMDL = LC = \Sigma\ WLA + \Sigma\ LA + MOS$

where ΣWLA is the sum of all wasteload allocations, ΣLA is the sum of all load allocations, and MOS is the margin of safety. The objective of the TMDL is to estimate allowable pollutant loads and to allocate these loads to known pollutant sources within the watershed so appropriate control measures can be implemented and the water quality standard achieved. The Code of Federal Regulations (40 CFR §130.2 (1)) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For inorganic sediment contamination, TMDLs are expressed as pounds per day using a load duration curve and as a mass of contaminants in a given mass of bed sediment. The load duration curve represents the maximum one-day load the water body can assimilate and maintain the water quality criterion at a given flow, while the given mass of metals per mass of sediment applies on any day in which the content in bed sediment is measured. For inorganic sediment, the TMDL is also expressed as percent of bed sediment that can be comprised of fine sediments.

6.2.1 TMDL Target Determination

In the case of inorganic sediment where the TMDL is targeting a narrative standard, a reference approach is taken. A series of United States Geological Survey (USGS) sampling stations and results for non-filterable residue (Appendix B) were used to calculate the 25th percentile of total suspended solids concentrations at various flows across the region in which Pond Creek is located. Using the data from these sites, the 25th percentile of total suspended solids concentrations is 5 mg/L. This concentration is used as a numeric translator for the narrative inorganic sediment standard. A more in-depth discussion of this procedure is outlined in Appendix C.

Dissolved metals targets were calculated based on the applicable chronic criterion for dissolved cadmium, lead and zinc at the watershed 25th percentile hardness of 160 mg/L.

6.2.2 Stepwise Explanation of How TMDL Calculations were Performed

6.2.2.1 Load Duration Curves

The following discussion provides a summary of the steps involved in the calculation of key components of the Pond Creek TMDLs for inorganic sediment.

Step 1: Develop a flow duration curve. A flow duration curve is a graph depicting the percent of time in which a given flow is equaled or exceeded. An estimated flow duration curve for Pond Creek was developed for this TMDL. A synthetic flow regime was developed based on the level of stream flow measured in gaged streams in the same region of the state, specifically the Ozark/Meramec Ecological Drainage Unit (EDU defined in Sections 2.1 and 6.1). The USGS gage stations for the Big Creek at Des Arc (07037000), South Fork Saline Creek near Perryville (07020550), East Fork Black River near Centerville (07061900), and the Bourbeuse River near High Gate, MO (07015720) were used to develop a flow duration curve based on flow per square mile in the drainage area (Figure 11). The graph of the normalized durations for the reference streams can be found in Appendix C.

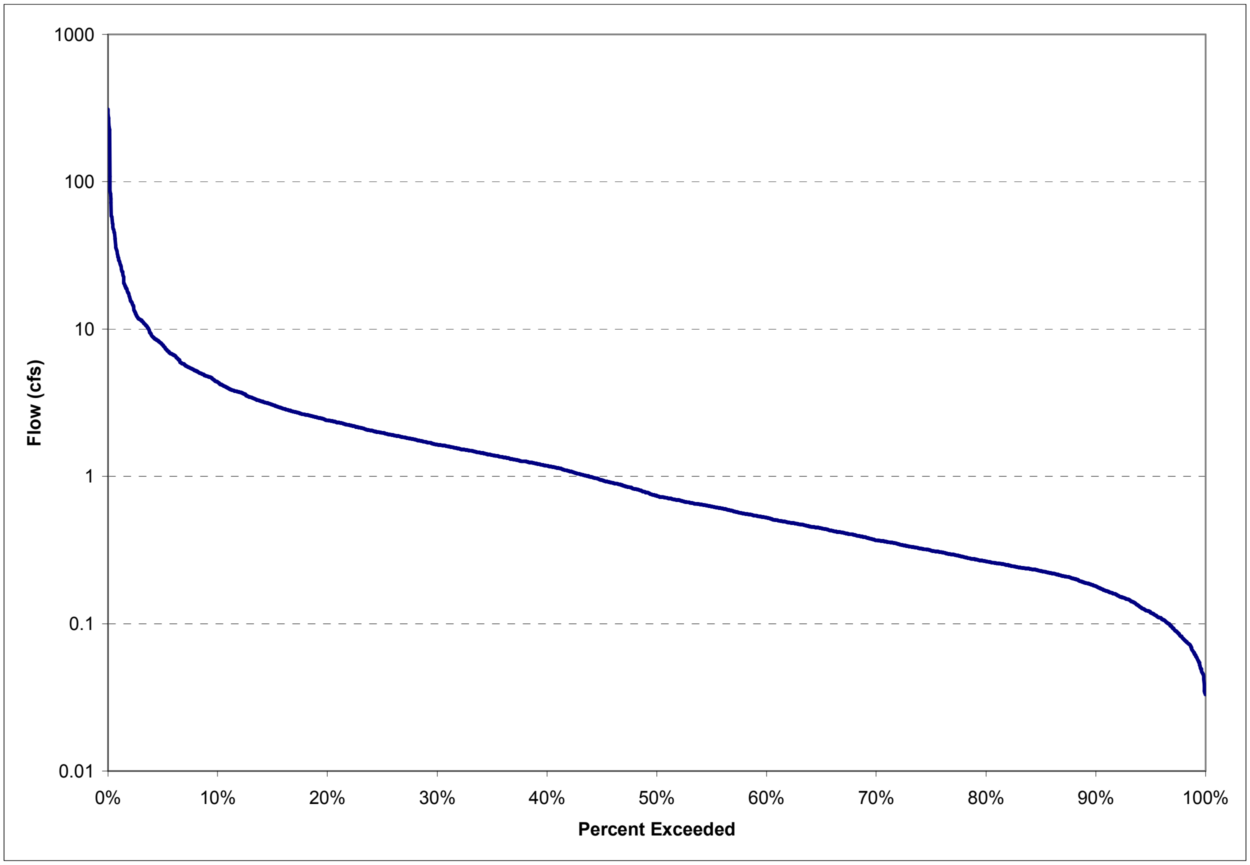
Step 2: Develop load duration curve (TMDL). Similar to a flow duration curve, the load duration curve depicts the percent of time in which a given inorganic sediment load is equaled or exceeded. When using the numeric inorganic sediment translator to calculate the load duration curve, the resulting curve also represents the TMDL. In brief, the load duration curve is developed from a regression of data points from throughout the Ozark/Meramec EDU that account for date, estimated flow, and inorganic sediment concentration. Loading is calculated in tons per square mile of watershed per day. From this, a target for inorganic sediment loading is calculated, based on the 25th percentile of total suspended solids concentrations in the region. Load duration curves were also calculated for dissolved cadmium, lead and zinc. Targets for dissolved metals were criteria-based on the 25th percentile of hardness data within the Ozark/Meramec EDU, which is 160 mg/L $CaCO_3$. Further details to this approach may be found in Appendix C and calculations are presented in Section 7. Data from Pond Creek necessary to populate current conditions on the load duration curve was collected by the department in the fall of 2008 and the spring of 2009.

Step 3: Calculate the margin of safety. The margin of safety can be either implicit or explicit. In this case, the margin of safety is both. The margin of safety for this TMDL is further explained in Section 7.7.

Step 4: Estimate current point source loading. It is known that abandoned mined lands are a historic point source contributor to Pond Creek's inorganic sediment impairment. The limited water quality data available for the Pond Creek watershed did not indicate currently occurring point source loading. If future monitoring indicates any change, such data can be used to calculate point source load reductions for the watershed.

Step 5: Calculate Wasteload Allocation. The wasteload allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. The wasteload allocation portion of the TMDL is an instream pollutant allocation expressed as pounds per day (lbs/day) and used to allocate pollutant loading to point sources of pollutants within the watershed. Such sources may be diverse and are predominantly subject to permitting requirements. However, as mentioned in Section 5.1, active and abandoned mine areas can be classified as point sources due to the nature of mining and milling activities, regardless if they are currently covered by a discharge permit (USEPA 1993a). The abandoned mine land areas from past mining may therefore collectively be considered a point source even though there are no State Operating Permits issued in the watershed. Mine tailings from these areas are historically thought to have been the main contributor of inorganic sediment to the impaired water body segment.

Figure 11. An estimated flow duration curve for Pond Creek.



The wasteload allocation is equal to the available load capacity after accounting for the margin of safety and load allocation. In the case of cadmium, lead and zinc, the predominant land uses (i.e., forest and grassland) contribute a negligible amount of loading of these metals to the watershed. This is generally supported by water quality data collected from water bodies not likely to be affected by the abandoned mine lands. Due to the extremely minor contribution of these metals from nonpoint sources within the watershed, it is reasonable to allocate the entire loading capacity for dissolved cadmium, lead and zinc to point sources.

In the case of inorganic sediment, the predominant land uses (i.e., forest and grassland) may contribute a minor amount of the overall inorganic sediment pollutant loading to the watershed. However, the amount of inorganic sediment loading from forest, grassland, and agricultural land use types is not as significant as that derived from the abandoned mine land areas. The lack of total suspended solids data makes it problematic to calculate the amount, however small, that other land uses contribute to pollutant loading of inorganic sediment. There is reassurance, however, that sediment runoff from forest and grassland areas is likely to be minor due to the stability and nature of the available vegetative cover. The abundance of vegetation in these areas reduces the erosional effects of stormwater runoff by limiting stormwater velocity, lessening raindrop impact and providing greater soil infiltration (USEPA 1993b). For these reasons, the amount of contribution from these sources is believed to be less than the explicit margin of safety used for this pollutant. Likewise, agricultural impacts are expected to be equally minimal due to the small percentage of land in the watershed (0.7 percent) that is in row or close-grown crops.

Therefore, due to the small contribution of inorganic sediment from nonpoint sources in the watershed, it is reasonable to allocate the entire loading capacity for inorganic sediment to point sources.

The wasteload allocation for dissolved cadmium, lead and zinc and inorganic sediment at any given percentile flow exceedance can be calculated from the TMDL load duration curve by solving Equation 5 for the wasteload allocation component:

Equation 6. WLA (lb/day) = TMDL (lb/day) – MOS (lb/day) – LA (lb/day)

where WLA equals wasteload allocation, MOS equals the margin of safety, and LA equals the load allocation.

Step 6: Estimate current nonpoint source loading. In Step 5 above, nonpoint source loading of inorganic sediment and heavy metals to the watershed are expected to be minor. This is generally supported by the lack of impairment for these pollutants in nearby streams and watersheds with similar land use types. Therefore, for the purposes of this TMDL, current nonpoint source loading of inorganic sediment and dissolved cadmium, lead and zinc is set to zero.

Step 7: Calculate load allocation. The load allocation (LA) is the maximum allowable amount of the pollutant that can be assigned to nonpoint sources. The load allocation is also an instream pollutant allocation expressed in pounds per day (lbs/day), similar to the wasteload allocation. It is used to allocate pollutant loading to nonpoint sources of pollutants within a watershed. Such sources may be diverse and difficult to identify and are not subject to permitting requirements. Because the predominant source of inorganic sediment and heavy metals loading to Pond Creek derives from point sources, the load allocation portion of the TMDL is set to zero.

Step 8: Estimate load reduction. Point source load reduction was calculated by subtracting the wasteload allocation (Step 5) from the current point source loading estimate (Step 4) as shown in the following equation:

Equation 7: Point source load reduction (lb/day) = Current point source load (lb/day) – Wasteload Allocation (lb/day)

The percent point source load reduction can be calculated using the following equation:

Equation 8: Percent point source load reduction = (point source load reduction [lb/day]/ Current point source loading [lb/day]) * 100

As stated in Step 6, load allocation reductions are not necessary because nonpoint source loading of inorganic sediment and heavy metals are expected to be minor. Results of all the aforementioned calculations are discussed in Section 7.

6.2.2.2 Bed Sediment Mass Targets

Sediment targets for cadmium, lead and zinc were set using the percent of those metals in a given mass of sediment such that the target level is consistent with the threshold effect concentration (MacDonald *et al*. 2000). While a threshold effect concentration level has not been established for barium, reduction in sediment concentrations of cadmium, lead and zinc should reduce

metals toxicity in Pond Creek. The inorganic sediment target is also represented by calculating the percent fine sediment by mass.

To address the impairment for inorganic sediment as percent fine sediment and cadmium, lead and zinc in bed sediment, a relationship was generated using data for percent fine sediment and the specific mass of sampled sediment from the stream bottom collected from control streams; West Fork of Huzzah Creek and Shoal Creek. This relationship is independent of segment location and refers to any location from which a sample is taken. As such, the bed sediment TMDLs are instantaneous and apply on any given day.

A percent fine sediment target of 15 percent was developed using the median of the 75th percentiles from each of the control sites on the reference streams. The load capacity curve and table (Figure 12, Table 11) were developed based on the mass of fine sediment that could be contained within a bottom sediment sample of a given mass. For example, a 100 mg bottom sediment sample should contain no more than 15 mg of fine sediment.

Bed sediment metal TMDLs for Shibboleth Branch were developed using the results of the percent fine sediment load capacity curve (Figure 12 and Table 11) and the metals equilibrium partitioning methodology (Section 4.3). Load capacities were calculated based on the percent of a given sediment sample mass that could be composed of cadmium, lead, and zinc such that the threshold effect levels for these metals was not exceeded. Because metals contamination in sediment is typically associated with the fine sediment fraction, the maximum load capacity for bed sediment metals should not be more than the allowable percentage of fine sediment in a given sample. To arrive at an acceptable concentration of bed sediment metals within a given sample, the fine sediment TMDL curve was multiplied by the metal-specific threshold effects concentration (TEC) as shown in Equation 9.

Equation 9. TMDL Mass Metal in Sediment = TMDL Mass Fine Sediment * Metal TEC

The resulting bed sediment load capacity curves for cadmium, lead, and zinc represent the maximum amount of those metals allowed in a given sample where the entire allowable fine sediment fraction are fine sediment metals. As with the percent fine sediment load capacity, the bed sediment load capacity values for cadmium, lead, and zinc apply on any given day.

6.2.3 Reduction Target

The advantage of load duration curve and bed sediment approaches is avoidance of the constraints associated with using a single-flow critical condition during the development of a TMDL. To determine the amount of load reduction necessary to comply with the chronic criterion for dissolved cadmium, lead and zinc, in-stream critical conditions were evaluated. According to the load duration curve, water quality data were only available at relatively low flow conditions in the Pond Creek watershed. Therefore, the percentage of pollutant load reduction was estimated based on this flow condition.

7. RESULTS OF TMDL AND POLLUTANT ALLOCATIONS

Following is a discussion of the results of the TMDL process for Pond Creek and an evaluation of potential sources and pollutant allocations. Section 6.2.2 discussed the specific steps taken to develop each of these components.

7.1 TMDL Calculations

The TMDLs for bed sediment cadmium, lead, zinc and percent fine sediment are shown in Figure 12. Table 11 provides a tabular expression of these TMDLs at varying masses of sediment in any particular sample. These TMDLs are mass dependant and apply at any point in either segment of Pond Creek.

Calculation of the regression for total suspended solids against flow within the Ozark/Meramec EDU yielded the following relationship:

Equation 10: Ln(sediment yield(lbs/day) = 1.25299*ln(flow(cfs)) + 2.4233 ($R^2 = 0.8263$)

Figure 12. TMDL for bed sediment: cadmium, lead, zinc and fine sediment.

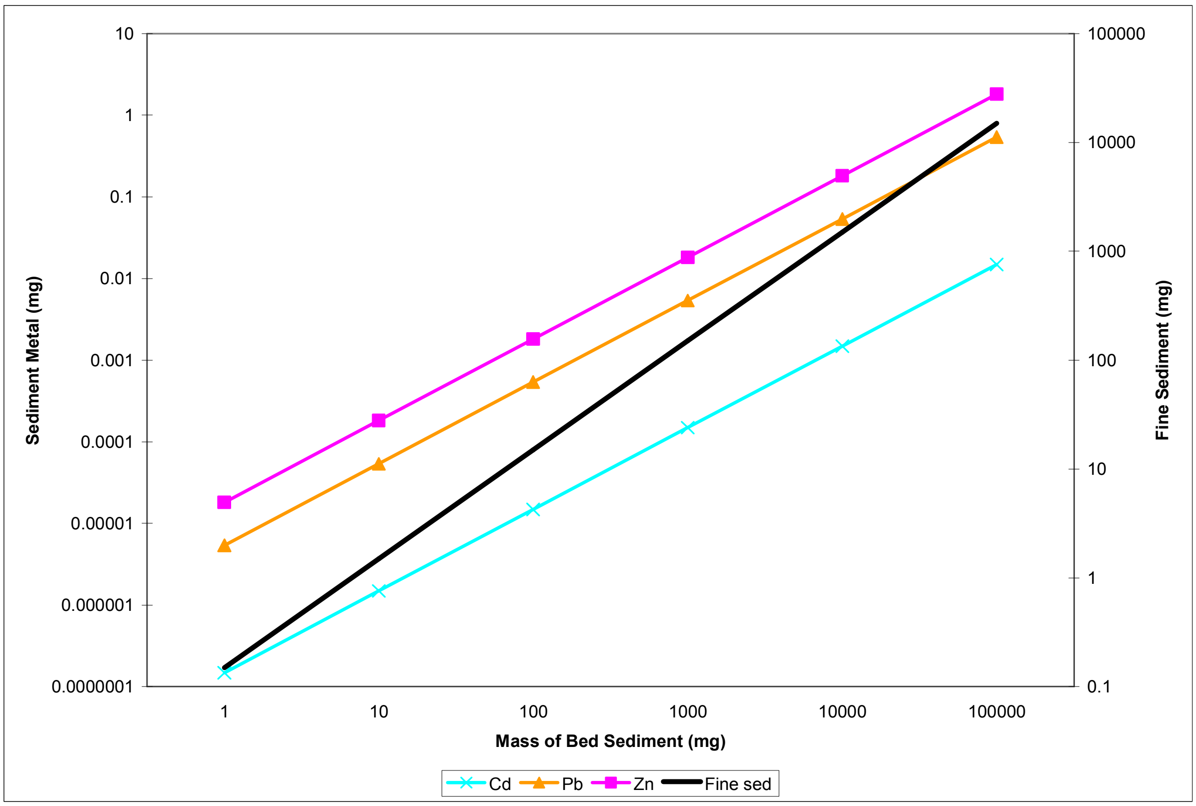


Table 11. Pond Creek bed sediment TMDLs.

Mass of Sample (mg)	*TMDL Mass Fine Sediment (mg)*	*TMDL Mass Cadmium (mg)*	*TMDL Mass Lead (mg)*	*TMDL Mass Zinc (mg)*
1	0.15	$1.485*10^{-7}$	$5.37*10^{-6}$	$1.815*10^{-5}$
10	1.5	$1.485*10^{-6}$	$5.37*10^{-5}$	$1.815*10^{-4}$
100	15	$1.485*10^{-5}$	$5.37*10^{-4}$	0.001815
1,000	150	$1.485*10^{-4}$	0.00537	0.01815
10,000	1,500	0.001485	0.0537	0.1815
100,000	15,000	0.01485	0.537	1.815

7.2 TMDL Pollutant Allocation and Reductions

Figure 13 shows the inorganic sediment load duration curve for Pond Creek. This load duration curve is the inorganic sediment TMDL. Section 6.2.2 discussed the specific steps taken to develop each of these components. As also mentioned in Section 6.2.2, the wasteload allocation component is equal to the available load capacity after accounting for the margin of safety and load allocation. Because the margin of safety for inorganic sediment is explicit (10 percent of the load capacity), the wasteload allocation is set at the load capacity minus the margin of safety and load allocation which is set at zero. In Figure 13, the area below the TMDL curve would therefore equal the wasteload allocation and margin of safety components at each flow exceedance range.

Figures 14, 15 and 16 present Pond Creek load duration curves for dissolved cadmium, lead and zinc. Tables 12 through 15 present Load Capacity (LC), Wasteload Allocation (WLA), Load Allocation (LA), and Margin of Safety (MOS) values for inorganic sediment and dissolved cadmium, lead and zinc. TMDL load capacity values were converted from tons/day to lbs/day by dividing by a conversion factor of 2,000.

The TMDL line for inorganic sediment was derived by adjusting the distribution of the sediment data from the Meramec/Ozark EDU such that the median of the new distribution is the same as the 25th percentile value of the unadjusted EDU data.

Equation 11: Sediment yield (lbs/day) = $e^{(1.25299*\ln(\text{flow(cfs)})+2.4233)}$

Any allocation of waste load allocations and load allocations will be made in terms of dissolved cadmium, lead and zinc, sediment cadmium, lead and zinc, suspended sediment, and percent fine bed sediment reductions. In calculating the TMDLs for these pollutants, the average condition was considered across seasons to establish both TMDL endpoints and desired reductions. To best represent the average condition, the criteria for dissolved cadmium, lead and zinc were multiplied by the median daily flow across all flow conditions. This is represented graphically by the integrated area under their respective load duration curves (Figures 14, 15 and 16) and in tabular form (Tables 13, 14 and 15). Bedded sediment targets are expressed graphically in Figure 12 and in tabular form in Table 11.

7.3 Wasteload Allocations for Pond Creek Watershed

The wasteload allocations for dissolved cadmium, lead and zinc, and sediment were estimated using Equation 6 provided in Section 6:

Cadmium (implicit Margin of Safety)
WLA (0.0003 lb/day) = TMDL (0.0003 lb/day) – LA (0.0 lb/day)

Lead (implicit Margin of Safety)
WLA (0.0041 lb/day) = TMDL (0.0041 lb/day) – LA (0.0 lb/day)

Zinc (implicit Margin of Safety)
WLA (0.1477 lb/day) = TMDL (0.1477 lb/day) – LA (0.0 lb/day)

Sediment (10 percent Margin of Safety)
WLA (4.36 lbs/day) = TMDL (4.85 lbs/day) – MOS (0.49 lbs/day) – LA (0.0 lb/day)

The wasteload allocations for dissolved cadmium, lead and zinc and inorganic sediment must be achieved at the outlets to each segment. As seen in Figures 13 through 16, wasteload allocation increases with increasing flow. The wasteload allocation for bedded sediment and metals in sediment must be met at any point in each segment.

Figure 13. Load duration curve for inorganic sediment in Pond Creek.

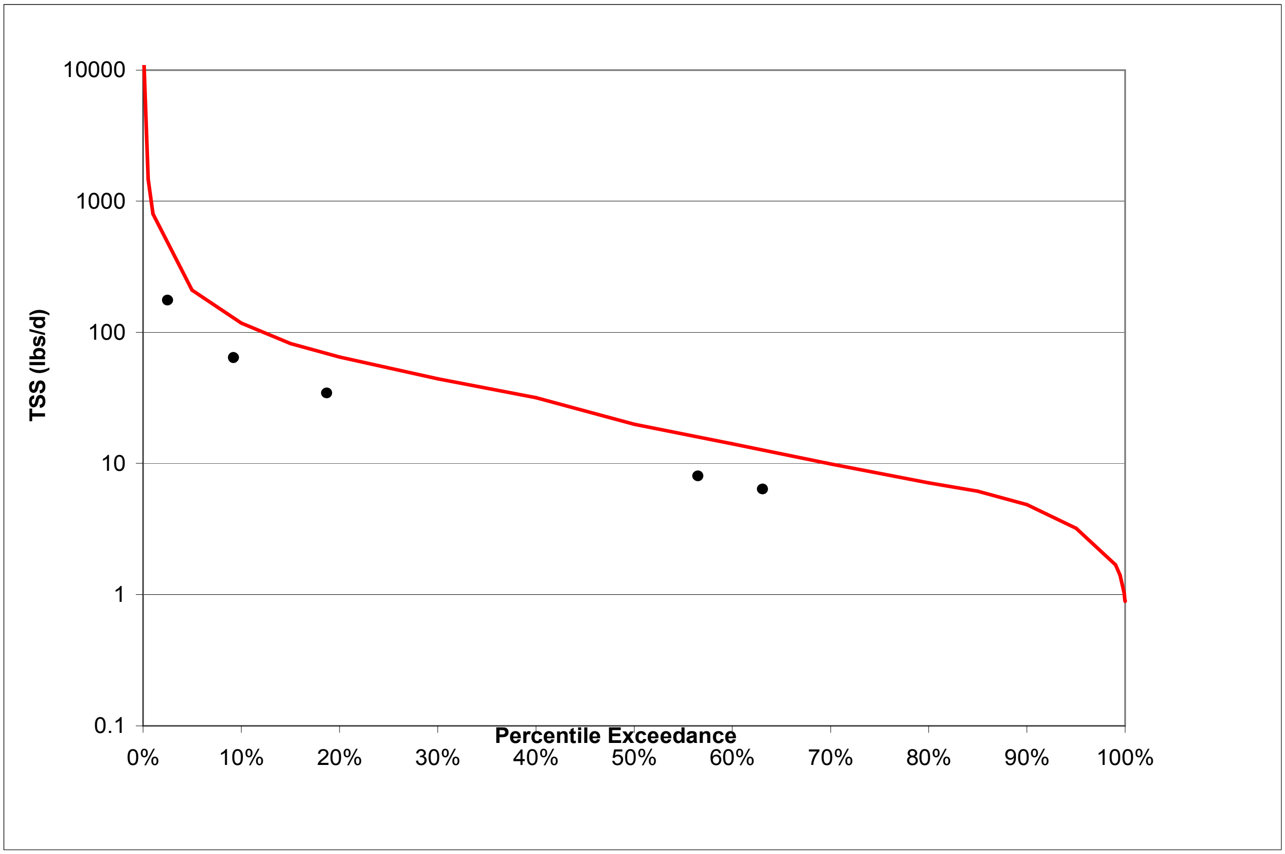


Table 12. Pond Creek TMDL for inorganic sediment.

% Flow Exceedence	*Estimated Flow (cfs)*	*Sediment TMDL (lbs/day)*	*Sediment MOS (lbs/day)*	*Sediment LA (lbs/day)*	*Sediment WLA (lbs/day)*
99	0.063	1.69	0.17	0	1.52
95	0.119	3.2	0.32	0	2.88
90	0.18	4.85	0.49	0	4.36
80	0.265	7.13	0.71	0	6.42
50	0.74	19.92	1.99	0	17.93
20	2.403	64.7	6.47	0	58.23
10	4.368	117.58	11.76	0	105.82
5	7.781	209.47	20.95	0	188.52
1	29.286	788.40	78.84	0	709.56

Figure 14. Load duration curve for dissolved cadmium in Pond Creek.

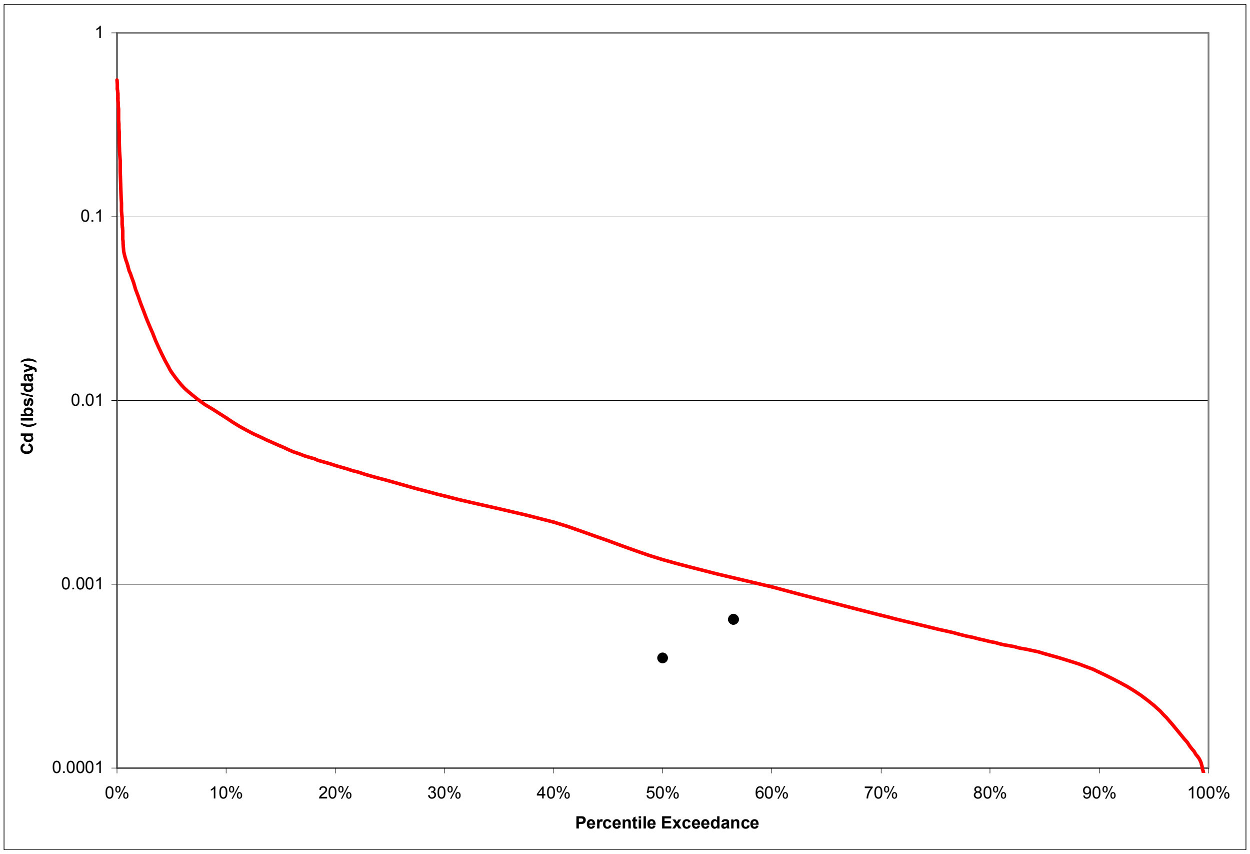


Table 13. Pond Creek TMDL for dissolved cadmium.

% Flow Exceedence	Estimated Flow (cfs)	Cadmium TMDL (lbs/day)	Cadmium MOS (lbs/day)	Cadmium LA (lbs/day)	Cadmium WLA (lbs/day)
99	0.063	0.0001	--	0	0.0001
95	0.119	0.0002	--	0	0.0002
90	0.18	0.0003	--	0	0.0003
80	0.265	0.0005	--	0	0.0005
50	0.74	0.0014	--	0	0.0014
20	2.403	0.0044	--	0	0.0044
10	4.368	0.008	--	0	0.008
5	7.781	0.0143	--	0	0.0143
1	29.286	0.0538	--	0	0.0538

Figure 15. Load duration curve for dissolved lead in Pond Creek.

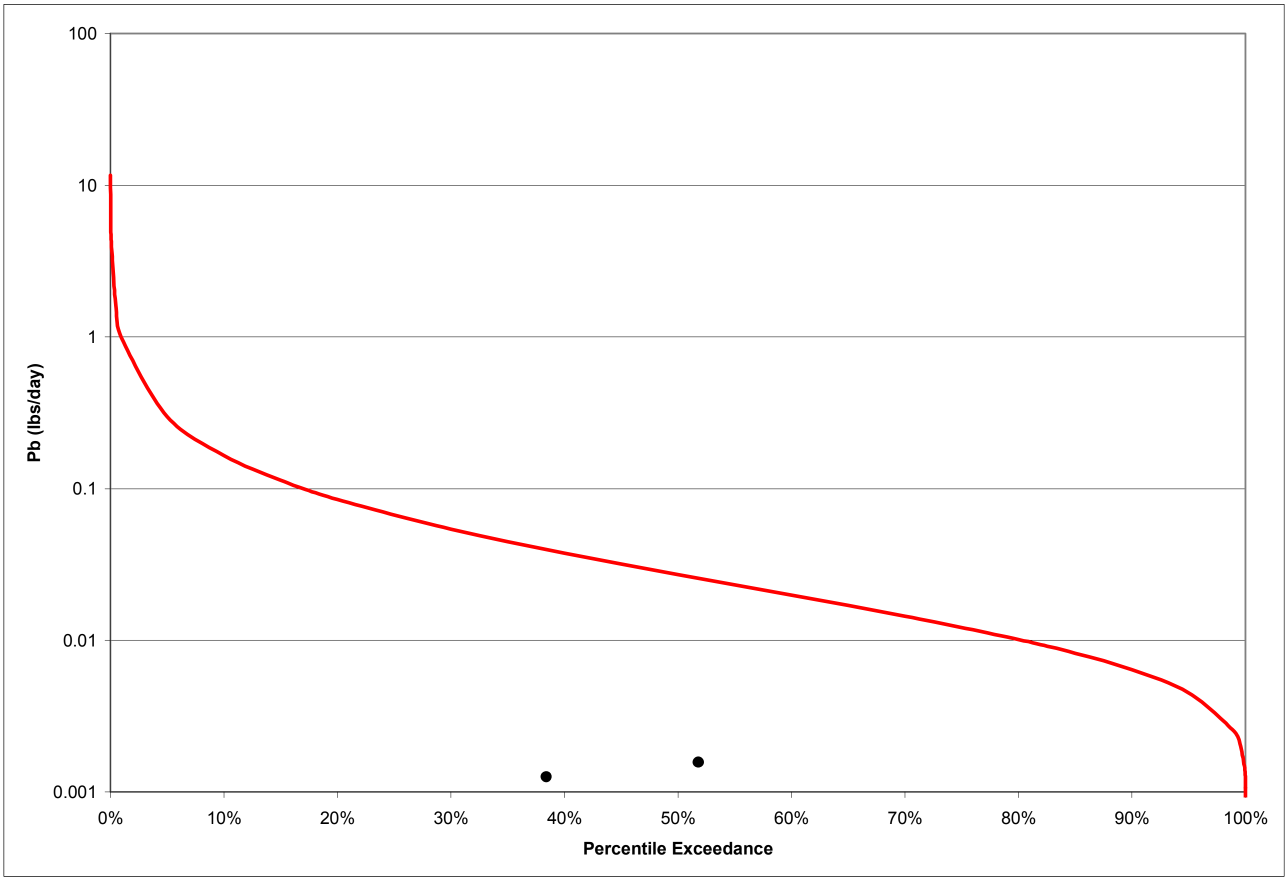


Table 14. Pond Creek TMDL for dissolved lead.

% Flow Exceedence	Estimated Flow (cfs)	Lead TMDL (lbs/day)	Lead MOS (lbs/day)	Lead LA (lbs/day)	Lead WLA (lbs/day)
99	0.063	0.0015	--	0	0.0015
95	0.119	0.0027	--	0	0.0027
90	0.18	0.0041	--	0	0.0041
80	0.265	0.006	--	0	0.006
50	0.74	0.0167	--	0	0.0167
20	2.403	0.0542	--	0	0.0542
10	4.368	0.0986	--	0	0.0986
5	7.781	0.1756	--	0	0.1756
1	29.286	0.6608	--	0	0.6608

Figure 16. Load duration curve for dissolved zinc in Pond Creek.

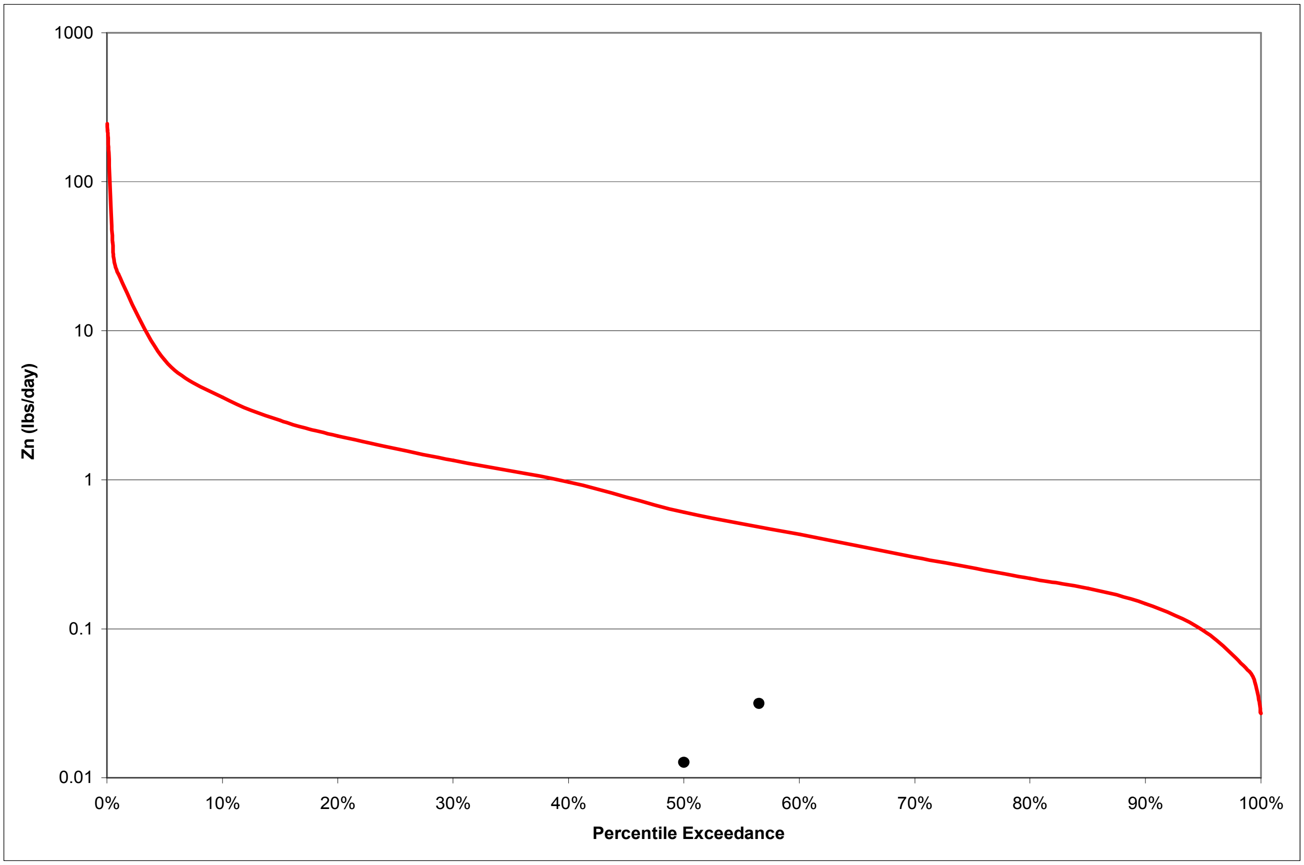


Table 15. Pond Creek TMDL for dissolved zinc.

% Flow Exceedence	*Estimated Flow (cfs)*	*Zinc TMDL (lbs/day)*	*Zinc MOS (lbs/day)*	*Zinc LA (lbs/day)*	*Zinc WLA (lbs/day)*
99	0.063	0.0515	--	0	0.0515
95	0.119	0.0975	--	0	0.0975
90	0.18	0.1477	--	0	0.1477
80	0.265	0.2172	--	0	0.2172
50	0.74	0.6064	--	0	0.6064
20	2.403	1.97	--	0	1.97
10	4.368	3.58	--	0	3.58
5	7.781	6.378	--	0	6.378
1	29.286	24.006	--	0	24.006

It should be noted, that while a WLA has been calculated for point sources, including any unpermitted abandoned mines, any allocation does not reflect an authorization to discharge from an unpermitted point source. Discharging pollutants to waters of the state without a permit is a violation of both state and federal clean water law. Should it become necessary to permit currently unpermitted abandoned mine areas, those areas must follow the department's permit application and antidegradation processes and will be evaluated in light of this TMDL.

The load reductions necessary to achieve water quality standards will be obtained from the abandoned mine lands area. However, while a wasteload allocation was calculated for the unpermitted abandoned mine land, any allocation given does not reflect an authorization to discharge from an unpermitted point source.

7.4 Load Allocation for Pond Creek Watershed

The dissolved cadmium, lead and zinc load allocation for the Pond Creek watershed was set at zero due to negligible nonpoint source loading of these metals to the impaired segments. The inorganic sediment load allocation for the Pond Creek watershed was also set at zero due to minor inorganic sediment loading to the impaired segments. As stated in Section 6.2.2.1, the amount of contribution from these sources is believed to be less than the explicit margin of safety used for this pollutant, therefore no allocation is necessary. The load allocation for the watershed is set at zero for these pollutants because activities within the watershed, present and historic, have disturbed, redisturbed, redistributed and reused materials associated with the abandoned mine lands captured in the point source wasteload allocation. Because these activities and resultant loads are already accounted for in the wasteload allocation, an additional load is not necessary as a load allocation.

While nonpoint sources of inorganic sediment and metals are minor or negligible under critical low-flow conditions, historic and legacy inorganic sediment and metals within the stream system can be sources of these pollutants, especially during higher flows. As conservative pollutants, inorganic sediment and metals do not degrade and historic pollutants can become re-suspended into the water column and carried downstream via natural fluvial processes. Significant inorganic sediment and metals suspension and re-deposition can occur during and immediately following high-flow storm events. This process allows previously unavailable inorganic sediment and metals to enter the water column and become a water quality concern as a secondary source of metals contamination. However, because the source of these materials is from abandoned mine areas and associated with the point source (wasteload allocation) portion of the TMDL, the load allocation does not reflect this secondary contribution to stream loading.

7.5 Point Source Load Reduction

Because the existing water quality data indicate non-detect levels for total suspended solids, no estimate of point source loading can be made. The accumulation of stream bed sediment, metals concentrations within the sediment, and low macroinvertebrate scores indicate a significant violation of the narrative criteria cited in Section 3.2. It is probable that sediment loading of the stream occurs mainly during high flow events that have not been captured by water quality sampling. If future monitoring yields significant loading of TSS, and if it can be reasonably ascribed to point source loading, point source load reductions will be calculated using equations 7 and 8 in Step 8 of Section 6.2.2.1.

For percent fine sediment cover in the stream bed, the anticipated WLA reduction from the point source (abandoned mine lands) was calculated by subtracting the median of the 75th percentile for cover in the control streams from the central median percent cover in Pond Creek.

Percent Reduction = [(% cover in Pond Creek – % cover in control streams)/ % cover in Pond Creek]*100
= [61 –15)/61] * 100
= 75 %

For heavy metals in fine bed sediment, the anticipated WLA reduction from the point source was calculated by subtracting the consensus based Threshold Effects Concentration (TEC) for each of the metals measured in sediment from their maximum respective sediment concentrations in Pond Creek.

Percent Reduction = $\frac{\text{max. sediment metal concentration (mg/kg)} - \text{TEC (mg/kg)}}{\text{max. sediment metal concentration (mg/kg)}} * 10$

Results of this calculation are found in Table 16.

Table 16. Percent reductions for heavy metals in Pond Creek sediments.

Metal	*Maximum Sediment Concentration (mg/kg)*	*Threshold Effect Concentration (mg/kg)*	*Percent Reduction*
Cadmium (Cd)	0.683	0.99	--
Lead (Pb)	96.8	35.8	63
Zinc (Zn)	525	121	83

7.6 Nonpoint Source Load Reduction

Because there are negligible nonpoint source loading of dissolved cadmium, lead and zinc and minor nonpoint source loading of inorganic sediment to the impairments in Pond Creek, no reduction in nonpoint source loading is necessary under this TMDL.

7.7 Margin of Safety

Federal regulations at 40 CFR §130.7(c)(1) require that TMDLs take into consideration a margin of safety (MOS) that is usually added to a TMDL to account for the uncertainties inherent in the calculations and data gathering. The margin of safety is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the margin of safety can be achieved through one of two approaches:

A. Explicit – Reserve a numeric portion of the load capacity as a separate term in the TMDL.

B. Implicit – Incorporate the margin of safety as part of the critical conditions for the wasteload allocation and the load allocation calculations by making conservative assumptions in the analysis.

This TMDL relies on both implicit and explicit margin of safety derived from a variety of calculations and assumptions. In deriving the dissolved cadmium, lead and zinc TMDLs, an implicit margin of safety was applied by using chronic water quality criteria for these metals and using the resulting values for both water column and interstitial water (porewater) targets. To set

inorganic sediment metal TMDLs for cadmium, lead and zinc, Threshold Effect Concentrations (TECs) for these metals in sediment were used. TECs should be used to identify sediments that are unlikely to be adversely affected by sediment-associated contaminants. In contrast, the Probable Effects Concentration (PEC) should be used to identify sediments that are likely to be toxic to sediment-dwelling organisms (MacDonald *et al.* 2000). TECs for metals toxicity in sediment was chosen over PECs because it is a level below which no toxicity should occur and is thus protective of chronic and sub-chronic exposure. The conservative assumptions and factors used in this method should account for any uncertainties in the loading calculations. The margin of safety for percent fine sediment was also implicit because the WLA percent reduction targets the 75th percentile of the reference population frequency distribution. Due to the lack of available inorganic sediment data, an explicit margin of safety of 10 percent was applied when deriving the inorganic sediment TMDLs.

7.8 Uncertainty Discussion

This TMDL document was prepared using data and assumptions that contribute a degree of uncertainty to the process. Following is a list of operating assumptions needed to support the TMDL analysis and calculations.

- The estimated flow for the outlets of each segment is directly related to the flow per square mile of the seven USGS gages used to develop the outlet flow record.
- The 25th percentile water hardness value of samples located in the area of Pond Creek is representative of those conditions within Pond Creek.
- Equilibrium partitioning calculations estimating pore water concentrations from bulk sediment were used to confirm the general nature of the impairment expressed as instream, aqueous phase concentrations.
- The contribution of dissolved cadmium, lead and zinc from nonpoint sources in the Pond Creek watershed is minor. The contribution of inorganic sediment from nonpoint sources is minor and that any amount of contribution from these sources is believed to be less than the explicit MOS used for this pollutant.
- The current point source loading estimates calculated using the maximum detected dissolved cadmium, lead and zinc concentration is representative of the actual point source loading at the low flow condition (90th percentile exceedance).

The load duration curve method was used to calculate pollutant specific TMDLs for the impaired segment of Pond Creek. Because the load duration curve method relies on measured water quality data, regional water hardness data, and a wide range of "flow exceedance" data, it represents a complete range of flows and pollutant loads anticipated in Pond Creek. However, the lack of water quality data at mid to high stream flows did not allow for calculation of pollutant load reductions at these flow conditions. These data would have been beneficial to include in the analysis since the majority of inorganic sediment and metals in sediment can be expected to be contributed during mid to high stream flow conditions. As result, there is some uncertainty as to the actual pollutant reductions necessary to achieve water quality standards during these stream conditions.

7.9 Consideration of Critical Condition and Seasonal Variation

Federal regulations at 40 CFR §130.7(c)(1) require TMDLs take into consideration seasonal variation in applicable standards. The impairment of Pond Creek is due to inorganic sediments

being carried into the water body through stormwater runoff. These conditions are more likely to occur during seasonal periods having significant precipitation. The TMDL load duration curve, however, represents flow under all possible stream conditions. The advantage of a load duration curve approach is that it avoids the constraints associated with using a single-flow critical condition during the development of the TMDL. Because the TMDL is applicable under all flow conditions, it is also applicable for all seasons. Seasonal variation is therefore implicitly taken into account within the TMDL calculations.

8. IMPLEMENTATION

Past barite mining in the Pond Creek watershed left a legacy of related land disturbance, including creation of barite tailings dams. When it rains, the water suspends the fine particles of sediment and metals and carries them to the waterways in the watershed. These particles impair aquatic life due to metals toxicity and/or through loss of habitat due to excessive sedimentation. The following implementation strategies should be considered to ensure the improvement of water quality within the Pond Creek watershed addressed by this TMDL.

8.1 Point Sources

Point source reductions are typically implemented through discharge permits administered through the Missouri State Operating Permit program to meet the requirements of Missouri's Water Quality Standards and State Operating Permits. The abandoned barite mine lands have been identified as one of the sources of the inorganic sediment impairment to Pond Creek. While the old barite mined areas are currently not covered by a Missouri State Operating Permit, future remedial actions must take into consideration the wasteload allocations established for inorganic sediment and metals found in this TMDL. These wasteload allocations and other requirements to improve water quality may be incorporated into any future Missouri State Operating Permits (either site-specific industrial or stormwater) or other appropriate enforceable documents.

Since the washing associated with active mining has long ago ceased, contributions of fines to the creek are no longer originating from the water impounded by King Arthur's Dam. Water seeping through this dam was observed by Water Protection Program staff during two 2009 site visits. The water was clear, even after the heavy rains that occurred in the area 2 to 3 days prior to the site visits.

Although small in size relative to the entire dam face, unvegetated portions of the face of King Arthur's Dam may be a potential source of inorganic sediment (See Section 5.1.3 and Figure 9) entering Pond Creek. It has been suggested that adding vegetative cover to the bare areas on the dam could aid in reducing water erosion and thereby reduce the potential of sediment from the dam face entering Pond Creek. However, as discussed in Section 2.5, barite tailings dams are different from traditional dams in many ways. Due to the nature of the material making up the dams, their face is often most stable at a 1:1 slope, compared to the 3:1 seen on traditional dams. In some places, the slope on the lower portion of King Arthur's Dam may be too steep to maintain the depth of topsoil needed to support permanent, non-woody vegetation on the dam faces. If soil of adequate depth was added to the lower dam face, it might simply slide downhill (MoDNR, Dam and Reservoir Safety Program, personal communication, April 16, 2010). Any work done on the dams or the spillways in the future should ideally involve implementation of appropriate best management practices (BMPs) to control soil erosion and reduce the amount of sediment reaching Pond Creek.

As mentioned previously, the reddish colored sediment in the impaired segment is from the red clay residuum from which the barite is mined. The pervasive soils in the area also originate from the same parent material, providing a constant source of erodible material along the creek, regardless of past or current contributions from the area associated with mining or the dam itself.

It is important to note that mining and the associated processing of barite in the watershed likely stopped at least 20 years ago. The last major disturbance in the headwaters of Pond Creek were likely in the early 2000s when a new landowner constructed a home on the east side of the lake impounded by King Arthur's Dam and raised the dam height (See Section 5.1.2). If best management practices were not employed to reduce soil erosion, these activities could have contributed to the fine layer of red sediment found on the Pond Creek substrate. However, the landowner reported that the area on which he built his home was largely bare of vegetation when he purchased the property, possibly from past mining-related activities (Ross Carrabino, landowner, personal communication June 28 and 29, 2010).

8.1.1 Federal Superfund Site

Pond Creek is in the Washington County Lead District – Potosi National Priority Listing (Superfund) site. The site encompasses an area greater than 45 square miles in the eastern portion of Washington County, Missouri. Soil and/or groundwater are contaminated with arsenic, barium, cadmium and lead resulting from mining, milling and smelting activities. A Remedial Investigation (RI) was initiated in January 2008. The RI will characterize the numerous tailings ponds and streams, determine the extent of groundwater contamination and characterize the residential surface soil. Superfund remedial actions may impact Pond Creek (Frances Klahr and Kathy Rangen, the department's Hazardous Waste Program, e-mail communications, Sept. 2 and 3, 2010, respectively).

8.1.2 Washington County Roads

Local unpaved roads are constructed in the ubiquitous Tiff soil type and are thus potential sources of the sediment in Pond Creek. The use of old mine tailings, or other combinations of rock and clay to resurface unpaved county roads, often provides easily erodible material during storm events. The county is encouraged to continue to follow best management practices when conducting road maintenance involving the Tiff soil series in order to minimize disturbance and subsequent contributions of sediment to Pond Creek. Without the current grading and additions of material to the surfaces of these steep, unpaved roads, they would quickly become impassable with gullies and ruts. Ideally, steep, unpaved county roads, like the one running along the east side of King Arthur's Dam, would be prioritized for paving in order to reduce the likelihood of stormwater carrying sediment to local creeks. However, paving roads is extremely costly and prioritization is likely based on many other factors besides grade, including level of use (i.e., traffic load).

8.2 Nonpoint Sources

Nonpoint source reductions are currently not necessary to reduce pollutant loading of inorganic sediment and metals to the Pond Creek watershed. Reductions obtained by implementing the wasteload allocations found in this TMDL should restore water quality in Pond Creek. However, BMPs employed within the watershed must continue to be implemented to ensure antidegradation requirements are met. Further nonpoint source reductions in the watershed may

be implemented in the future through BMPs funded wholly or in part by Section 319 grants[15] or various cost-share opportunities available through the department's Soil and Water Conservation Program and the federal Natural Resources Conservation Service.

Field observation and inventory of the area would be needed to determine whether or not all grassland areas in the watershed are grazed, the condition of that grassland, and if the extrapolated rate of 0.28 cattle per acre is accurate. However, physically canvassing an entire watershed would likely require manpower and landowner consent beyond the department's means. The information needed to make this assessment may or may not be available through the local Soil and Water Conservation District (SWCD) or Natural Resources Conservation Service office, and then only if landowners voluntarily enrolled and participated in the available programs and adopted associated best management practices (BMPs) to reduce soil loss using cost-share. Considering the soil type in the immediate watershed, adoption of BMPs to ensure adequate erosion control in grazing areas would be prudent. However, a records survey by the Washington County SWCD revealed few participants in the county (Kelly Farris, Washington County SWCD, e-mail communication, Dec. 2009).

9. MONITORING PLAN

A sediment and biological monitoring study was completed for Pond Creek in the spring of 2009. The department intends to conduct follow up biological monitoring on Pond Creek to confirm the status of the macroinvertebrate community. Biomonitoring is scheduled for both segments of this stream for the 2011 State Fiscal Year, along with monitoring for heavy metals in sediment. Any additional water quality data that is collected in the Pond Creek watershed will be evaluated in light of this TMDL.

10. REASONABLE ASSURANCE

In most cases, "Reasonable Assurance" in reference to TMDLs relates to the certainty to which point sources will reduce pollutant loading to impaired water body segments. Currently, there are no permitted point source discharges of inorganic sediment and heavy metals within the Pond Creek watershed. However, the abandoned barite mine lands are considered a point source for the purposes of this TMDL. Wasteload allocations to improve water quality may be incorporated into a Missouri State Operating Permit (either site-specific industrial or stormwater) or other appropriate enforceable document to ensure wasteload allocation reductions are achieved. Any assurances that nonpoint source contributors of inorganic sediment will implement measures to reduce their contribution in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint sources can be found in Section 8.2 of this TMDL.

11. PUBLIC PARTICIPATION

EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). Before finalizing TMDLs, the department's Water Protection Program notified the public that a comment period was open for 45 days, from June 8 to July 23, 2010, by placing a Public Notice, the draft TMDL, and the associated TMDL Information Sheet on the department's website, thus

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[15] Under section 319, State, Territories and Indian Tribes receive grant money that support a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects.

making them available to anyone with access to the Internet. Public notices to comment on the draft TMDL are also distributed via mail and electronic mail to stakeholders in the watershed, or other potentially impacted parties. In this case, those receiving the public notice announcement included the Missouri Clean Water Commission, the Missouri Water Quality Coordinating Committee, Washington County Commission, 29 Stream Team volunteers in the area, the Potosi Independent Journal, and the two state legislators representing Washington County. After the comment period closed, the department reviewed all comments, wrote and sent responses to the comments, and edited the TMDL as appropriate, before submitting the TMDL and supporting documents to EPA's Region 7 office in Kansas City, Kan., for their review.

12. ADMINISTRATIVE RECORD AND SUPPORTING DOCUMENTATION

An administrative record on the Pond Creek TMDL has been assembled and is being kept on file with the department. It includes any studies, data, modeling and calculations on which this TMDL is based, as well as any documents related to public participation including all written comments and responses.

13. REFERENCES

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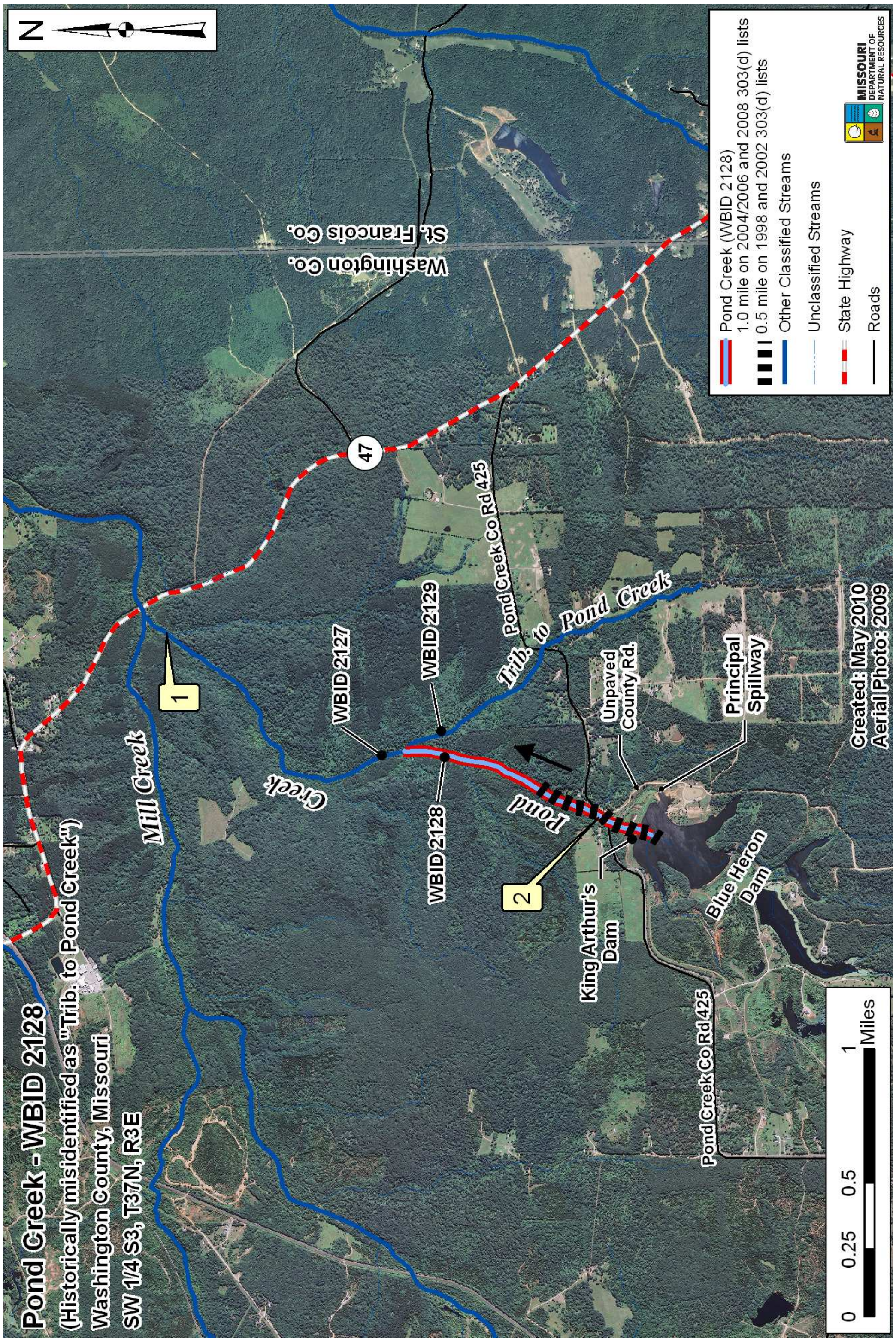
Appendix A

Map of Sampling Sites on Pond Creek and Associated Water Column Chemistry Data

A-1: Aerial Photograph-based Map of Pond Creek (Both Segments) Sampling Sites



Appendix A (*continued*)

Map of Sampling Sites on Pond Creek and Associated Water Column Chemistry Data

A-2: Water Column Chemistry Data from Pond Creek Used in TMDL Development.

Sample Site	Sample No	Yr	Mo	Dy	Time	Flow	C	DO	pH	SC	TSS	TRB	DBA	DCD	DPB	DZN	Hard
1	0810004*	2008	9	24	1010	5.37	16	8	8.1	366		7.18	618	0.1	0.12	5.61	202
2	0810006*	2008	9	24	1355	1.56	17	7.2	8.3	200		1.55	557	0.1	0.12	3.18	100
1	0901087**	2009	1	22	1015	2.01					2.499						
2	0901086**	2009	1	22	930	0.73					2.499						
1	0912002*	2009	3	23	1145	1.27	12	11.2	8.4	435	2.499	1	612	0.2	0.25	8.46	220
2	0912003*	2009	3	23	1306	0.51	14	10.4	8.2	326	2.499	3	469	0.2	0.25	9.83	158
2	0912191**	2009	3	25	1405	0.55					2.499						
2	0911098**	2009	3	26	1125	0.3	12.4		8	316	2.499						
2	0910280**	2009	4	28	1315	2.5	17.7	9.4	8.2	184	2.499						

Sample Site	Site Names	Additional Note	WBID
1	Pond Cr. nr. Mouth	ESP's Site #1	2127
2	Pond Cr. @ Pond Creek Rd.	ESP's Site #2; just downstream from (i.e., north of) Pond Cr Rd bridge	2128

Where:	Means:
*	Collected by DNR ESP staff
**	Collected by DNR WPP/ WQMA Section staff
Flow	in cubic feet per second (cfs)
C	Water Temperature in degrees Celsius
DO	Dissolved Oxygen (mg/L)
pH	Measurement of acidity/alkalinity
SC	Specific Conductance (µS)
TSS	Total Suspended Solids (mg/L)
TRB	Turbidity (in NTUs)
DBA	Dissolved Barium (µg/L)
DCD	Dissolved Cadmium (µg/L); PEC = 4.98 mg/kg dry weight
DPB	Dissolved Lead (µg/L); PEC = 128 mg/kg dry weight
DZN	Dissolved Zinc (µg/L); PEC = 459 mg/kg dry weight
Hard	Hardness as CaCO3

Appendix B

Pond Creek TMDL Methodology

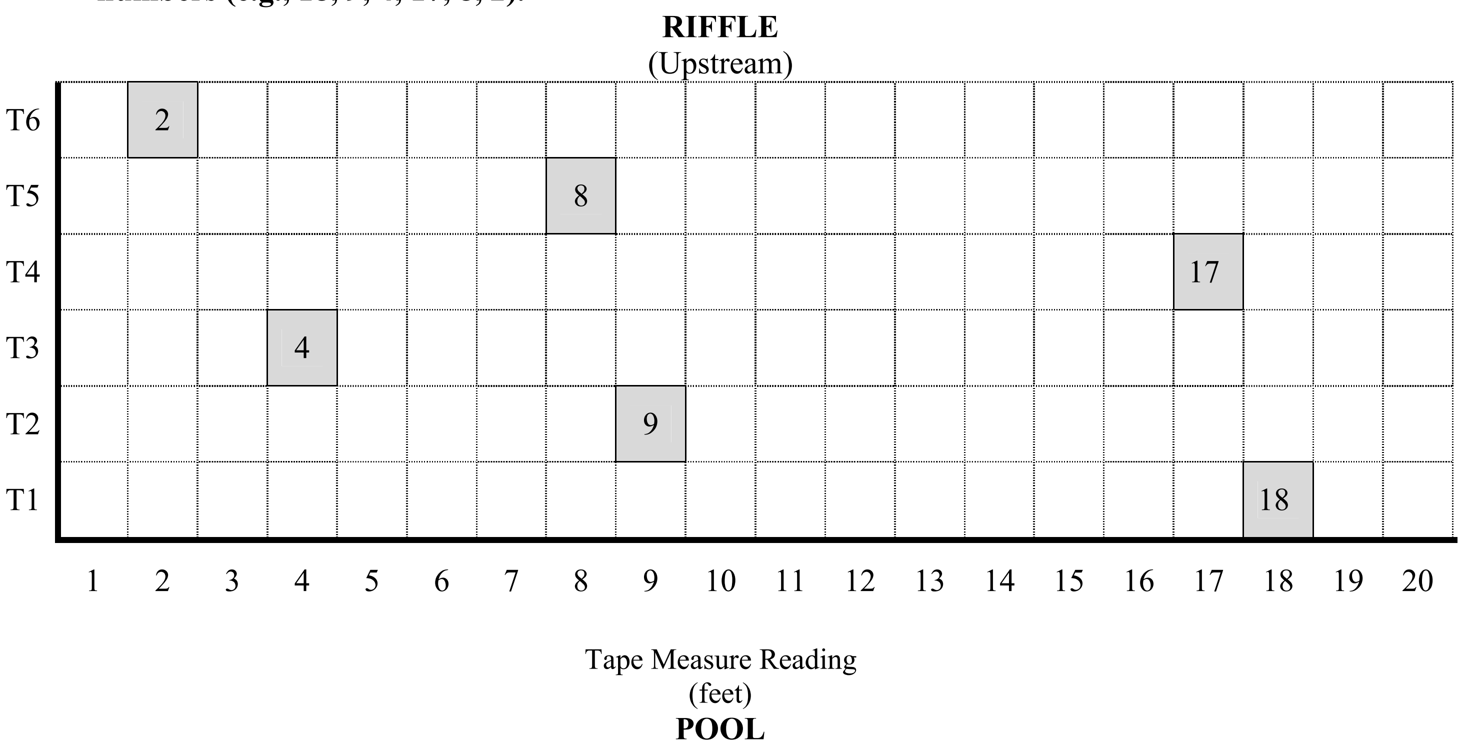
Fine Sediment Coverage Estimations

The relative percentage of fine sediment (<2.0 mm) coverage was visually estimated for each station. The visual estimates were conducted within a metal square (quadrat) that was randomly located in sample areas called grids (Figure B-1). Each station contained three grids. This method allowed for estimation and comparison of benthic fine sediment between stations.

In order to ensure sampling method uniformity, grids were located at lower margins of riffles or runs and the upper margin of pool habitats in areas of relatively laminar flow. This arrangement or placement of grids was similar to previous fine sediment assessment projects done by the WQMS (MDNR-WQMS Reports: Flat River 2001, MDNR 2001; Upper Big River 2001-2002, MDNR 2003a). Water velocity was no greater than 0.5 feet per second (fps), which allows fine sediment sized particles (<2.0mm) to settle from transport after high flow events, according to the Hjulstrøm Diagram (Hjulstrøm 1939; See "References" section of this TMDL) for threshold transport and settling velocities. A Marsh-McBirney flow meter was used to determine maximum velocity within the proposed grid. Depths did not exceed three (3.0) feet. Grids did not include eddies, bends, downstream of vegetation, or large obstructions that have turbulent flow.

Once a suitable area was identified, a virtual grid was constructed (Figure B-1). A 100' tape measure anchored across the stream became the downstream transverse edge of a virtual grid of

Figure B-1. Virtual grid of transects (T) and quadrats (in gray, numbered) for estimating percent fine sediment. Example: stream 20' wide; quadrat placement based on random numbers (e.g., 18, 9, 4, 17, 8, 2).



six contiguous transects. Each transect was 12" deep and as wide as the useable grid and was identified by holding a retractable tape measure perpendicular to the 100' tape. The useable grid width included the width of the stream with relatively laminar flow that excluded eddies, vegetation, and large obstructions. Random numbers, equating to one foot increments, were drawn to determine where the quadrat was placed along each transect. The quadrat was placed within the transect, with the downstream edge contacting the downstream transect edge. Two observers estimated/recorded the percent of fine sediment within the quadrat. The estimates were accepted and recorded if the two observations were within a ten percent margin of error or rejected and repeated until the margin of error was reached. Another random number was drawn and the quadrat was randomly placed in the next transect upstream where the next observation was made. This continued until fine sediment was estimated in each of the six quadrats (one per transect) and the results are summarized in Table B-1.

Table B-1. Fine sediment deposition measurements in Pond Creek and control streams (percentages).

Pond Creek #2	*Pond Creek #1*	*W. Fk Huzzah Cr.*	*Shoal Cr.*
92	25	3	3
99	55	3	1
95	10	3	1
95	40	7	1
90	5	7	7
85	50	1	1
98	27	4	23
95	45	3	20
95	10	2	23
95	25	3	87
90	55	70	80
89	13	53	63
95	75	3	3
95	23	1	15
87	70	5	7
97	93	7	20
90	27	2	8
97	23	3	13

To address the impairment for inorganic sediment as percent fine sediment and cadmium, lead and zinc in sediment, a relationship was generated using percent fine sediment data and the specific mass of sampled sediment from the stream bottom. This relationship is independent of segment location and refers to the location of the sample taken. As such, the bed sediment load capacities are instantaneous and apply on any given day.

The percent fine sediment target of 15.45 percent was developed using control sites in reference streams that are described in Table 3 in Section 4.2.1 of this TMDL. The load capacity curve and table were developed based on the mass of fine sediment that could be contained within a bottom sediment sample of a given mass.

The bed sediment metal load capacity was generated using the equilibrium partitioning methodology described in the TMDL. The load capacity was calculated based on the percent of a sediment mass that could be composed of metals such that the Threshold Effect Concentration was not exceeded. As with the percent fine sediment target, this load capacity applies on any given day.

Load Duration Curves

To develop the dissolved cadmium, lead and zinc load duration curve (LDC) for Pond Creek, a synthetic flow duration curve was developed based on the level of stream flow measured in gaged streams within the same region of the state. The U.S. Geological Survey (USGS) gage stations used are shown in Table B-2.

Table B-2. USGS Gage stations used to develop flow regime for segment 2128.

USGS No.	Site Name	Drainage Area (mi^2)
07037000	Big Creek @ Des Arc	99.6
07020550	S Fork Saline Cr near Perryville	55.3
07061270	E Fk Black R near Centerville	52.2
07061900	Logan Cr at Ellington	139
07015720	Bourbeuse River near High Gate	135

The median discharge per square mile was calculated for these streams and applied to the upper segment of Pond Creek based its drainage area of 4.47 mi^2.

Once a flow regime was calculated, an estimated Total Suspended Solids (TSS) concentration was derived from streams with measured concentrations in the region (Table B-3). The LDC for suspended sediment was generated based on the 25^{th} percentile of all TSS data. The LDCs for dissolved cadmium, lead and zinc were generated based on the numeric criterion calculated using the 25^{th} percentile of hardness data in the region (Table B-4).

Table B-3. Water quality sites used for calculation of 25^{th} percentile total hardness and total suspended solids.

USGS No. or Agency	Site Name	Hardness Data	TSS Data
Mo DNR	Big R. @Washington State Park	X	
Mo DNR	Big R. 0.7 mi.bl. Eaton Br.	X	
Mo DNR	Big R. DS of Clear Cr.	X	
Mo DNR	Big R. just ab. Furnace Cr.	X	
Mo DNR	Big R. near Belgrade	X	
07018100	Big R. near Richwoods	X	X
Mo DNR	Big R. upstream of Bonne Terre	X	
Mo DNR	Big R. upstream of Mill Creek	X	
375232090325800	Big River @ Bone Hole	X	X
Mo DNR,	Big River @ St Francois State Park	X	
07012700, Mo DNR	Big River at Irondale	X	X
Mo DNR	Big River below Desloge	X	X
Mo DNR	Big River just bl. Cedar Cr.	X	

USGS No. or Agency	Site Name	Hardness Data	TSS Data
Mo DNR	Big River just bl. Flat River	X	
Mo DNR	Big River nr. Washington St.Pk.	X	
07016500	Bourbeuse R. above Union	X	X
Mo DNR	Brazil Cr. @ Campground	X	X
Mo DNR	Brazil Cr. @Thicky Ford	X	
07017605	Coonville Creek nr. Mouth	X	X
Mo DNR	Courtois Cr. @ Goodwater,ab.Viburnum tailings	X	X
07014200	Courtois Cr. @Hwy 8	X	X
Mo DNR	Courtois Cr. ab. Bass Creek Resort	X	
Mo DNR	Courtois Cr. ab. Indian Cr. @old Hwy C	X	
Mo DNR	Courtois Creek 4 mi. N. of Courtois, MO.	X	
Mo DNR	Crooked Cr. @ Chandler Rd.	X	X
Mo DNR	Crooked Cr. @ County Line	X	
Mo DNR	Crooked Cr. just ab. trib. from Casteel Mine	X	
Mo DNR	Crooked Creek 3 mi. WSW of Viburnum, Mo.	X	X
Mo DNR	Cub Cr. 2 mi. NE of Courtois, Mo.	X	
Mo DNR	E. Fk. Huzzah Cr. @ CR 530	X	X
Mo DNR	E. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	X	
Mo DNR	Eaton Br. @CR nr mouth	X	
Mo DNR	Eaton Branch nr mouth	X	
07019220	Fenton Cr.@Hwy 141	X	X
07019120	Fishpot Cr.@Valley Park	X	X
Mo DNR	Flat River Cr.@Hwy B	X	X
Mo DNR, UMR	Flat River Cr.@Main Street,Flat River,MO	X	X
Mo DNR	Flat River Cr.@Rivermines	X	X
Mo DNR	Fountain Farm Branch nr. Mouth	X	X
Mo DNR	Fourche Renault Cr. ab. Hwy 185	X	
Mo DNR	Furnace Cr. 0.4 mi US of Big R.	X	
Mo DNR	Goose Cr. 3.2 mi.bl. Tailings pond	X	
07019185	Grand Glaize Cr. @Valley Park	X	X
07140104	Heads Cr. @ Hwy. 30	X	X
Mo DNR	Huzzah Cr. @ US of Davisville Rd.	X	
07014000	Huzzah Cr. @Hwy 8	X	X
07014300	Huzzah Cr. nr mouth	X	X
Mo DNR	Indian Cr. 4.5 mi.bl. Mary's Cr.	X	
Mo DNR	Indian Cr.@ old Hwy C, 2 mi.bl. Viburnum tailings	X	
07019072	Kiefer Cr. nr. Ballwin	X	X
Mo DNR	L. Courtois Cr. 100 yds.bl. Mary's Cr.	X	
Mo DNR	L. Courtois Cr. 50 yds.ab. Mary's Cr.	X	
Mo DNR	Mary's Cr. 30 yds. Ab. Mouth	X	
07019317	Mattese Cr. @Ringer Rd. bridge	X	X
Mo DNR	Meramec R. @ MDC Short Bend CA	X	
07019280	Meramec R. @ Paulina Hills,MO.	X	X
07010350	Meramec R. above Cook Station		X
07019000	Meramec R. nr. Eureka	X	X
07014500	Meramec R. nr. Sullivan,MO.	X	X
Mo DNR	Mill Cr. @Tiff,Mo.	X	

USGS No. or Agency	Site Name	Hardness Data	TSS Data
Mo DNR	Mill Creek ab. Hwy 47	X	
Mo DNR	Mill Creek bl. Tiff	X	
Mo DNR	Mineral Fork @Hwy 47	X	
Mo DNR	Mineral Fork ab. Kingston CA	X	
Mo DNR	Mineral Fork bl. Hwy F	X	
Mo DNR	Pond Cr. nr. Mouth	X	X
Mo DNR	Shaw Br. @ St. Joe S. P.	X	X
Mo DNR	Shibboleth Cr. @ CR 410(Johnson Rd.) xing #2	X	X
Mo DNR	Shibboleth Cr. @ CR 410(Johnson Rd.) xing #4	X	X
Mo DNR	Shibboleth Cr. @Hwy E		X
Mo DNR	Shibboleth Cr. 0.4 mi. bl. Hwy. E	X	X
Mo DNR	Shibboleth Cr. Nr Heritage Rd.		X
Mo DNR	Shoal Cr. nr. Big Shoal Creek Rd./Stotler Rd. inters.	X	X
Mo DNR	Shoal Creek 2 mi. NE of Davisville, Mo.	X	
Mo DNR	Spring Cr. @ CR 416		X
07019260	Sugar Cr. Nr. Paulina Hills	X	X
Mo DNR	Trib. To Old Mines Cr.(Salt Pine Cr.)@ Hwy.21	X	X
Mo DNR	Trib. To Old Mines Creek @ Hwy. 21	X	X
Mo DNR	Trib. To Pond Cr. @ Pond Creek Rd.	X	X
Mo DNR	W. Fk. Huzzah Cr. @ Hwy. 32	X	
Mo DNR	Trib. To Turkey Cr. Nr. Mouth		X
Mo DNR	Trib2. To Turkey Cr. Nr. Mouth		X
Mo DNR	Turkey Cr. @Hwy 47, ab. Chat pile		X
Mo DNR	W. Fk. Huzzah Cr. @ Hwy. 32		X
Mo DNR	W. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	X	
07019090	Williams Cr. nr.Peerless Park	X	

Table B-4. Data used in calculating applicable hardness value.

Org	Site	Site Name	Hardness
MDNR	2080/8.5	Big R. @Washington State Park	268
MDNR	2080/8.5	Big R. @Washington State Park	238
MDNR	2080/55.6	Big R. 0.7 mi.bl. Eaton Br.	263
MDNR	2080/55.6	Big R. 0.7 mi.bl. Eaton Br.	192
MDNR	2080/73.4	Big R. DS of Clear Cr.	210
MDNR	2080/73.4	Big R. DS of Clear Cr.	220
MDNR	2080/73.4	Big R. DS of Clear Cr.	150
MDNR	2080/71.8	Big R. just ab. Furnace Cr.	168
MDNR	2080/71.6	Big R. near Belgrade	240
MDNR	2080/71.6	Big R. near Belgrade	240
MDNR	2080/71.6	Big R. near Belgrade	160
USGS	2074/53.0	Big R. near Richwoods	210
USGS	2074/53.0	Big R. near Richwoods	170
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	310
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	260
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	190
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	190
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	290
USGS	2074/53.0	Big R. near Richwoods	200
USGS	2074/53.0	Big R. near Richwoods	140
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	180
USGS	2074/53.0	Big R. near Richwoods	180
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	140
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	300
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	260
USGS	2074/53.0	Big R. near Richwoods	290
USGS	2074/53.0	Big R. near Richwoods	140
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	310
USGS	2074/53.0	Big R. near Richwoods	150
USGS	2074/53.0	Big R. near Richwoods	190
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	200
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	210
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	190
MDNR	2080/20.4	Big R. upstream of Bonne Terre	261
MDNR	2080/20.4	Big R. upstream of Mill Creek	297
MDNR	2080/20.4	Big R. upstream of Mill Creek	229
USGS	2080/48.6	River River @ Bone Hole	170
USGS	2080/48.6	River River @ Bone Hole	290
USGS	2080/48.6	River River @ Bone Hole	240
USGS	2080/48.6	River River @ Bone Hole	160
USGS	2080/48.6	River River @ Bone Hole	200
USGS	2080/48.6	River River @ Bone Hole	220
USGS	2080/48.6	River River @ Bone Hole	330
USGS	2080/48.6	River River @ Bone Hole	320
USGS	2080/48.6	River River @ Bone Hole	240
MDNR	2080/32.4	BigRiver @ St. Francois State Park	264
MDNR	2080/32.4	BigRiver @ St. Francois State Park	234
USGS	2080/65.5	Big River at Irondale	130
USGS	2080/65.5	Big River at Irondale	190
USGS	2080/65.5	Big River at Irondale	180

Org	Site	Site Name	Hardness
USGS	2080/65.5	Big River at Irondale	140
USGS	2080/65.5	Big River at Irondale	160
USGS	2080/65.5	Big River at Irondale	160
USGS	2080/65.5	Big River at Irondale	210
USGS	2080/65.5	Big River at Irondale	209
USGS	2080/65.5	Big River at Irondale	162
MDNR	2080/42.5	Big River below Desloge	264
MDNR	2080/42.5	Big River below Desloge	304
MDNR	2080/42.5	Big River below Desloge	213
MDNR	2080/68.3	Big River just bl. Cedar Cr.	240
MDNR	2080/68.3	Big River just bl. Cedar Cr.	170
MDNR	2080/41.9	Big River just bl. Flat River	247
MDNR	2080/41.9	Big River just bl. Flat River	228
MDNR	2080/11.6	Big River nr. Washington St. Pk.	287
USGS	2034/21.5	Bourbeuse R. above Union	95
USGS	2034/21.5	Bourbeuse R. above Union	73
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	170
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	110
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	97
USGS	2034/21.5	Bourbeuse R. above Union	69
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	160
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	110
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	66
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	190
USGS	2034/21.5	Bourbeuse R. above Union	71
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	75
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	80
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	170
USGS	2034/21.5	Bourbeuse R. above Union	63
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	110
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	59
USGS	2034/21.5	Bourbeuse R. above Union	100
USGS	2034/21.5	Bourbeuse R. above Union	88
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	84
USGS	2034/21.5	Bourbeuse R. above Union	160
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	100
MDNR	1983/12.5	Brazil Cr. @ Campground	137
MDNR	1983/12/5	Brazil Cr. @ Campground	116
MDNR	1983/0.8	Brazil Cr. @ Thicky Ford	176
MDNR	1983/0.8	Brazil Cr. @ Thicky Ford	193
USGS	2177/0.2	Coonville Creek nr. Mouth	270
USGS	2177/0.2	Coonville Creek nr. Mouth	210
USGS	2177/0.2	Coonville Creek nr. Mouth	190
USGS	2177/0.2	Coonville Creek nr. Mouth	160
USGS	2177/0.2	Coonville Creek nr. Mouth	280
USGS	2177/0.2	Coonville Creek nr. Mouth	260
USGS	2177/0.2	Coonville Creek nr. Mouth	250
USGS	2177/0.2	Coonville Creek nr. Mouth	220
USGS	2177/0.2	Coonville Creek nr. Mouth	260
USGS	2177/0.2	Coonville Creek nr. Mouth	110
USGS	2177/0.2	Coonville Creek nr. Mouth	140
MDNR	1947/2.0/1.0	Courtois Cr. @ Goodwater, ab. Viburnum	143
MDNR	1947/2.0/1.0	Courtois Cr. @ Goodwater, ab. Viburnum	83.7
USGS	1943/15.7	Courtois Cr. @ Hwy 8	210
USGS	1943/15.7	Courtois Cr. @ Hwy 8	210
USGS	1943/15.7	Courtois Cr. @ Hwy 8	210

Org	Site	Site Name	Hardness
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	160
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	110
USGS	1943/15.7	Courtois Cr. @ Hwy 8	140
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	250
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	230
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	240
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	240
USGS	1943/15.7	Courtois Cr. @ Hwy 8	78
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	130
USGS	1943/15.7	Courtois Cr. @ Hwy 8	240
USGS	1943/15.7	Courtois Cr. @ Hwy 8	150
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	190
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	230
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	140
MDNR	1943/5.1	Courtois Cr. ab. Bass Creek Resort	183
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	150
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	190
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	170
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	130
MDNR	1943/23.4	Courtois Creek 4 mi. N. of Courtois, MO	260
MDNR	1943/23.4	Courtois Creek 4 mi. N. of Courtois, MO	170
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	353
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	465
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	192
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	325
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	332
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	280
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	320
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	246

Org	Site	Site Name	Hardness
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	259
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	260
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	362
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	364
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	243
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	351
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	423
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	820
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	549
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	593
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	398
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	261
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	179
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	427
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	274
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	163
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	295
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	383
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	548
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	368
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	240
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	200
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	318
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	172
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	220
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	150
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	234
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	184
MDNR	1926/1.0	E. Fk. Huzzah Cr. @ CR 530	183
MDNR	1926/1.0	E. Fk. Huzzah Cr. @ CR 530	153
MDNR	1925/2.3	E. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	220
MDNR	1925/2.3	E. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	160
MDNR	2166/0.2	Eaton Br. @ CR nr mouth	539
MDNR	2166/0.2	Eaton Br. @ CR nr mouth	321
MDNR	2166/0.2	Eaton Br. @ CR nr mouth	536
MDNR	2166/0.05	Eaton Branch nr mouth	597
MDNR	2166/0.05	Eaton Branch nr mouth	422
MDNR	2166/0.05	Eaton Branch nr mouth	375
MDNR	2166/0.05	Eaton Branch nr mouth	715
MDNR	2166/0.05	Eaton Branch nr mouth	581
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	120
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	420

Org	Site	Site Name	Hardness
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	200
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	310
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	300
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	95
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	320
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	120
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	100
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	290
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	340
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	140
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	390
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	450
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	610
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	158
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	365
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	98
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	480
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	422
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	140
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	550
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	150
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	530
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	500
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	220
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	92
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	510
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	430
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	150
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	600
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	600
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	130
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	450
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	170
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	570
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	510
USGS	2186/1.7	Fishpot Cr. @ Valley Park	190
USGS	2186/1.7	Fishpot Cr. @ Valley Park	48
USGS	2186/1.7	Fishpot Cr. @ Valley Park	220
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	65

Org	Site	Site Name	Hardness
USGS	2186/1.7	Fishpot Cr. @ Valley Park	190
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	340
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	86
USGS	2186/1.7	Fishpot Cr. @ Valley Park	190
USGS	2186/1.7	Fishpot Cr. @ Valley Park	240
USGS	2186/1.7	Fishpot Cr. @ Valley Park	45
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	72
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	260
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	200
USGS	2186/1.7	Fishpot Cr. @ Valley Park	42
USGS	2186/1.7	Fishpot Cr. @ Valley Park	85
USGS	2186/1.7	Fishpot Cr. @ Valley Park	150
USGS	2186/1.7	Fishpot Cr. @ Valley Park	170
USGS	2186/1.7	Fishpot Cr. @ Valley Park	290
USGS	2186/1.7	Fishpot Cr. @ Valley Park	160
USGS	2186/1.7	Fishpot Cr. @ Valley Park	170
USGS	2186/1.7	Fishpot Cr. @ Valley Park	170
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	45
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	200
USGS	2186/1.7	Fishpot Cr. @ Valley Park	150
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	66
USGS	2186/1.7	Fishpot Cr. @ Valley Park	300
USGS	2186/1.7	Fishpot Cr. @ Valley Park	250
USGS	2186/1.7	Fishpot Cr. @ Valley Park	87
USGS	2186/1.7	Fishpot Cr. @ Valley Park	200
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	60
USGS	2186/1.7	Fishpot Cr. @ Valley Park	330
USGS	2186/1.7	Fishpot Cr. @ Valley Park	100
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	160
USGS	2168/5.9	Flat River Cr. @ Hwy B	120180
USGS	2168/5.9	Flat River Cr. @ Hwy B	240

Org	Site	Site Name	Hardness
USGS	2168/5.9	Flat River Cr. @ Hwy B	140
USGS	2168/5.9	Flat River Cr. @ Hwy B	160
USGS	2168/5.9	Flat River Cr. @ Hwy B	210
USGS	2168/5.9	Flat River Cr. @ Hwy B	240
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	99
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	279
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	305
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	97
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	104
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	188
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	219
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	422
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	185
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	202
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	238
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	76
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	144
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	221
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	242
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	309
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	186
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	359
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	240
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	191
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	85
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	195
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	138
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	281
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	214
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	153
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	220
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	172
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	100
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	160
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	100
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	316
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	133
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	359
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	307
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	101
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	122
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	385
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	319

Org	Site	Site Name	Hardness
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	540
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	495
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	686
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	789
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	95
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	259
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	321
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	381
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	225
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	460
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	254
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	740
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	502
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	379
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	317
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	139
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	389
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	124
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	313
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	269
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	194
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	400
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	277
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	180
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	480
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	300
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	180
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	100
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	450
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	126
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	376
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	389
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	138
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	95
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	171
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	239
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	1030
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	203
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	189
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	705
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	83
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	276
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	330

Org	Site	Site Name	Hardness
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	517
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	495
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	281
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	453
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	323
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	339
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	124
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	385
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	146
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	273
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	198
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	100
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	153
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	250
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	189
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	120
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	260
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	160
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	200
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	100
MDNR	3657/0.1	Fountain Farm Branch nr. Mouth	215
MDNR	3657/0.1	Fountain Farm Branch nr. Mouth	231
MDNR	2084/1.8	Fourche Renault Cr. ab. Hwy 185	205
MDNR	2084/1.8	Fourche Renault Cr. ab. Hwy 185	147
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	280
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	280
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	240
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	268
MDNR	2010/1.0	Goose Cr. 3.2 mi. bl. Tailings pond	235
MDNR	2010/1.0	Goose Cr. 3.2 mi. bl. Tailings pond	173
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	280
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	75
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	390
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	350
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	120
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	280
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	330
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	220
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	320
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	100
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	240
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	320
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	220

Org	Site	Site Name	Hardness
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	220
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	170
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	190
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	585
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	380
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	320
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	140
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	260
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	190
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	260
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	390
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	370
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	290
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	230
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	410
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	360
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	240
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	360
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	170
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	530
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	130
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	340
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	370
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	410
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	330
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	330
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	140
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	200
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	290
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	280
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	310
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	480

Org	Site	Site Name	Hardness
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	370
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	360
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	380
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	150
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	190
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	160
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	210
USGS	2181/0.3	Heads Cr. @ Hwy. 30	260
USGS	2181/0.3	Heads Cr. @ Hwy. 30	280
MDNR	1903/18.2	Huzzah Cr. @ US of Davisville Rd.	225
MDNR	1903/18.2	Huzzah Cr. @ US of Davisville Rd.	209
MDNR	1903/18.2	Huzzah Cr. @ US of Davisville Rd.	224
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	170
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	180
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	170
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	140
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	160
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	206
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	189
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	203
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	86
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	220
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	140
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	220
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	180

Org	Site	Site Name	Hardness
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	220
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	190
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/1.3	Huzzah Cr. nr mouth	170
USGS	1903/1.3	Huzzah Cr. nr mouth	210
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	440
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	214
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	254
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	176
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	170
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	158
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	212
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	174
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	182
MDNR	1946/0.1	Indian Cr. @ old Hwy C, 2 mi. bl. Viburnum	260
MDNR	1946/0.1	Indian Cr. @ old Hwy C, 2 mi. bl. Viburnum	310
MDNR	1946/0.1	Indian Cr. @ old Hwy C, 2 mi. bl. Viburnum	210
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	91
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	120
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	280
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	320
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	64
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	81
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	250
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	310
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	100
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	86
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	310
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	230
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	75
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	80
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	64
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	280

Org	Site	Site Name	Hardness
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	561
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	297
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	151
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	108
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	322
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	296
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	85
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	340
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	330
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	230
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	110
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	320
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	350
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	140
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	330
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	350
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	65
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	380
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	180
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	270
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
MDNR	2002/1.7	L. Courtois Cr. 100 yds. bl. Mary’s Cr.	533
MDNR	2002/1.8	L. Courtois Cr. 100 yds. bl. Mary’s Cr.	209
MDNR	2002/1.8	L. Courtois Cr. 100 yds. bl. Mary’s Br.	222
MDNR	3661/0.1	Mary’s Cr. 30 yds. ab. Mouth	492
MDNR	3661/0.1	Mary’s Cr. 30 yds. ab. Mouth	619
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	67
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	67
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	300
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	300
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	240
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	43
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	51
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	160
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	320
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	360
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	120
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	280
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	310

Org	Site	Site Name	Hardness
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	180
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	320
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	62
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	270
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	240
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	92
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	230
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	250
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	415
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	204
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	120
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	267
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	280
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	240
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	155
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	615
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	195
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	210
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	380
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	140
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	300
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	260
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	60
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	270
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	430
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	84
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	370
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	370
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	88
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	260
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	120
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	340
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	340
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	195
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	215
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	185
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	66
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210

Org	Site	Site Name	Hardness
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	86
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	230
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180

Org	Site	Site Name	Hardness
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	220
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	220
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	240
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	83
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	120
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180

Org	Site	Site Name	Hardness
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	110
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	45
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	130
USGS	2185.12.3	Meramec R. nr. Eureka	220
USGS	2185.12.3	Meramec R. nr. Eureka	210
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	230
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	120
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	210
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	260
USGS	2185.12.3	Meramec R. nr. Eureka	130
USGS	2185.12.3	Meramec R. nr. Eureka	86
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	230
USGS	2185.12.3	Meramec R. nr. Eureka	230
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	92
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	210

Org	Site	Site Name	Hardness
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	91
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	210
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	110
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	72
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	130
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	120
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	150
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	120
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200

Org	Site	Site Name	Hardness
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	100
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	100
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	100
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210

Org	Site	Site Name	Hardness
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	110
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	120
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	220
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	110
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	230
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	226
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	272
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	169
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	186
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	249
MDNR	2118/8.5	Mill Creek ab. Hwy 47	256
MDNR	2118/8.5	Mill Creek ab. Hwy 47	160
MDNR	2118/2.9	Mill Creek bl. Tiff	244
MDNR	2118/2.9	Mill Creek bl. Tiff	189
MDNR	2081/5.5	Mineral Fork @ Hwy 47	250
MDNR	2081/5.5	Mineral Fork @ Hwy 47	194
MDNR	2081/5.5	Mineral Fork @ Hwy 47	261

Org	Site	Site Name	Hardness
MDNR	2081/5.5	Mineral Fork @ Hwy 47	190
MDNR	2081/5.5	Mineral Fork @ Hwy 47	176
MDNR	2081/5.5	Mineral Fork @ Hwy 47	223
MDNR	2081/5.5	Mineral Fork @ Hwy 47	207
MDNR	2081/5.5	Mineral Fork @ Hwy 47	240
MDNR	2081/2.5	Mineral Fork ab. Kingston CA	245
MDNR	2081/2.5	Mineral Fork ab. Kingston CA	200
MDNR	2081/12.5	Mineral Fork bl. Hwy F	249
MDNR	2081/12.5	Mineral Fork bl. Hwy F	192
MDNR	2127/0.1	Pond Cr. nr. Mouth	202
MDNR	2127/0.1	Pond Cr. nr. Mouth	220
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	330
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	206
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	426
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	412
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	135
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	184
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	281
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	885
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	237
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	236
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	605
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	201
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	561
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	465
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	196
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	185
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	180
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	320
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	160
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	198
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	184
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	243
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	206
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	189
MDNR	2120/2.3	Shibboleth Cr. 0.4 mi. bl. Hwy E	124
MDNR	2120/2.3	Shibboleth Cr. 0.4 mi. bl. Hwy E	173
MDNR	1934/6.1	Shoal Cr. nr. Big Shoal Creek Rd./Stotler Rd.	213
MDNR	1934/6.1	Shoal Cr. nr. Big Shoal Creek Rd./Stotler Rd.	171
MDNR	1934/5.2	Shoal Creek 2 mi. NE of Davisville, Mo..	240
MDNR	1934/5.2	Shoal Creek 2 mi. NE of Davisville, Mo..	160
USGS	2191/0.8	Sugar Cr. nr. Paulina Hills	200
USGS	2191/0.8	Sugar Cr. nr. Paulina Hills	240

Org	Site	Site Name	Hardness
MDNR	2113/0.1	Trib. To Old Mines Cr. (Salt Pine Cr.)@	242
MDNR	2113/0.1	Trib. To Old Mines Cr. (Salt Pine Cr.)@	272
MDNR	2114/0.1	Trib. To Old Mines Creek @ Hwy. 21	235
MDNR	2114/0.1	Trib. To Old Mines Creek @ Hwy. 21	232
MDNR	2128/0.8	Trib To Pond Cr. @ Pond Creek Rd.	100
MDNR	2128/0.8	Trib To Pond Cr. @ Pond Creek Rd.	158
MDNR	1923/0.1	W. Fk. Huzzah Cr. @ Hwy. 32	146
MDNR	1923/0.1	W. Fk. Huzzah Cr. @ Hwy. 32	121
MDNR	1922/3.2	W. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	220
MDNR	1922/3.2	W. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	130
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	210
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	250
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	180
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	89
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	78
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	260
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	73
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	160
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	53
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	250
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	220
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	71
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	130
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	210
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	190
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	280
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	140
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	200
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	54
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	83
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	250
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	84
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	290
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	280
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170

Org	Site	Site Name	Hardness
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	260
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	85
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240

Org	Site	Site Name	Hardness
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	140
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	190
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170

Appendix C

Reference Approach to Develop Suspended Sediment TMDL Load Duration Curves

Overview

This procedure is used when a lotic system is placed on the 303(d) impaired water body list for a pollutant and the designated use being addressed is aquatic life. In cases where pollutant data for the impaired stream is not available a reference approach is used. The target for pollutant loading is the 25th percentile calculated from all data available within the ecological drainage unit (EDU) in which the water body is located. Additionally, it is also unlikely that a flow record for the impaired stream is available. If this is the case a synthetic flow record is needed. In order to develop a synthetic flow record, calculate an average of the log discharge per square mile of USGS gaged rivers within the region. (Ideally, the drainage area for each of these should be entirely contained within the EDU. However, due to the small size of the Pond Creek watershed, and the lack of gaging stations in smaller watersheds within the Ozark/Meramec EDU, four of the five gaging stations used in this study are outside the EDU but within the Ozark ecoregion.) From this synthetic record develop a flow duration from which to build a load duration curve for the pollutant within the EDU.

From this population of load durations follow the reference method used in setting nutrient targets in lakes and reservoirs. In this methodology the average concentration of either the 75th percentile of reference lakes or the 25th percentile of all streams in the region is targeted in the TMDL. For most cases available pollutant data for reference streams is also not likely to be available. Therefore follow the alternative method and target the 25th percentile of load duration of the available data within the EDU as the TMDL load duration curve. During periods of low flow the actual pollutant concentration may be more important than load. To account for this during periods of low flow the load duration curve uses the 25th percentile of EDU concentration at flows where surface runoff is less than 1 percent of the stream flow. This results in an inflection point in the curve below which the TMDL is calculated using this reference concentration.

Methodology

The first step in this procedure is to locate available pollutant data within the area of interest. These data along with the instantaneous flow measurement taken at the time of sample collection for the specific date are recorded to create the population from which to develop the load duration. Both the date and pollutant concentration are needed in order to match the measured data to the synthetic flow record.

Secondly, collect average daily flow data for gages with a variety of drainage areas for a period of time to cover the pollutant record. From these flow records normalize the flow to a per square mile basis. Average the daily discharge for each day in the period of record. For each gage record used to build this synthetic flow record calculate the Nash-Sutcliffe statistic (see box below) to determine if the relationship is valid for each record. This relationship must be valid in

order to use this methodology. This new synthetic record of flow per square mile is used to develop the load duration for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow.

Nash-Sutcliffe Statistic

$$E = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} (Q_o^t - \overline{Q_o})^2}$$

E = efficiency of model: 100% indicates that model is perfectly matched to observed data
Q_o^t = observed discharge at time t
Q_m^t = modeled discharge for time t
$\overline{Q_o}$ = average of observed discharges

The watershed-size normalized data for the individual gages were calculated and compared to a pooled data set including all of the gages. The result of this analysis is displayed in the following figure and table:

Table C-1: Nash-Sutcliffe Statistics for Reference Gages

Stream	USGS gage #	Watershed area (mi^2)	Nash-Sutcliffe Statistic (%)
Big Creek	07037000	99.6	92
Bourbeuse River	07015720	135	91
E Fork Black River	07061270	52.2	82
Logan Creek	07061900	139	99
S Fork Saline Creek	07020550	55.3	98

This demonstrates the pooled data set can confidently be used as a surrogate for the EDU analyses.

The next step is to determine the target range for inorganic sediment. All data points within the EDU that include sediment concentrations concurrent with flow are compiled. The distribution of sediment is recalculated so that the median value of the adjusted distribution is equal to the 25th percentile of the original distribution while the minimum values remain constant. From the adjusted range, the load is calculated *[(mg/L) * (cfs) * 5.395 = lbs/day]* and log transformed. A regression calculation is performed against the log of the instantaneous flow. Results are found in Figure C-2:

Figure C-1: Modeled and Reference Flow Duration Curves

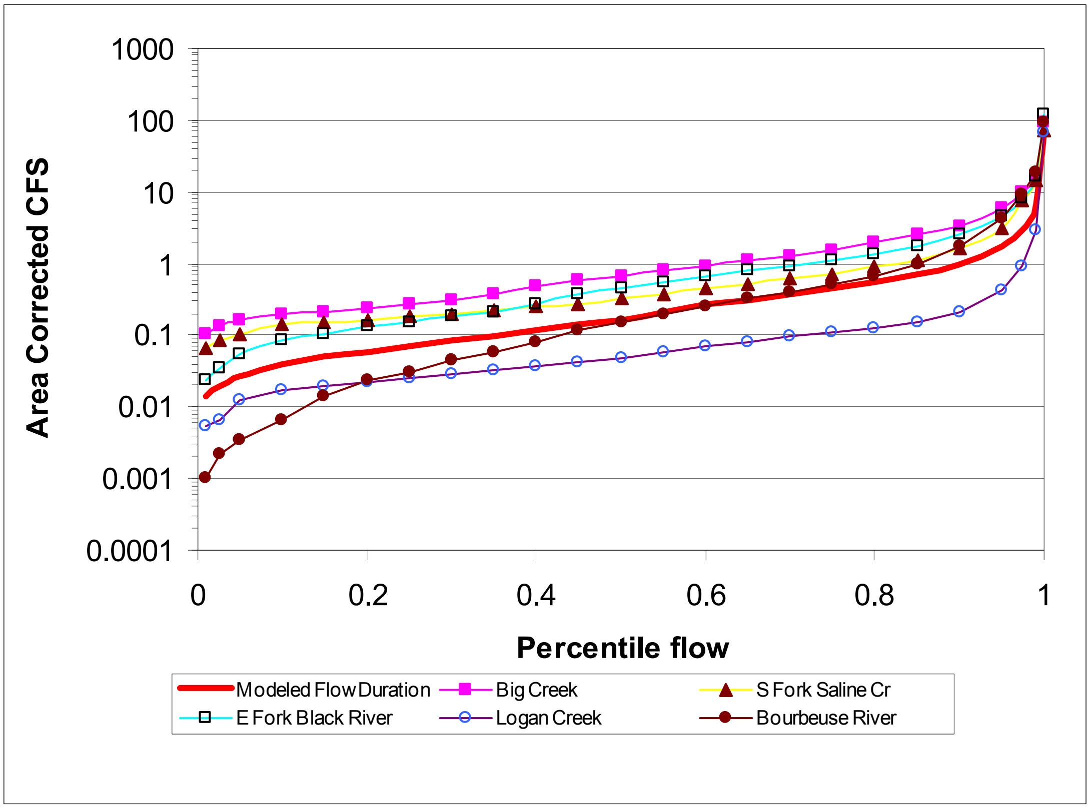
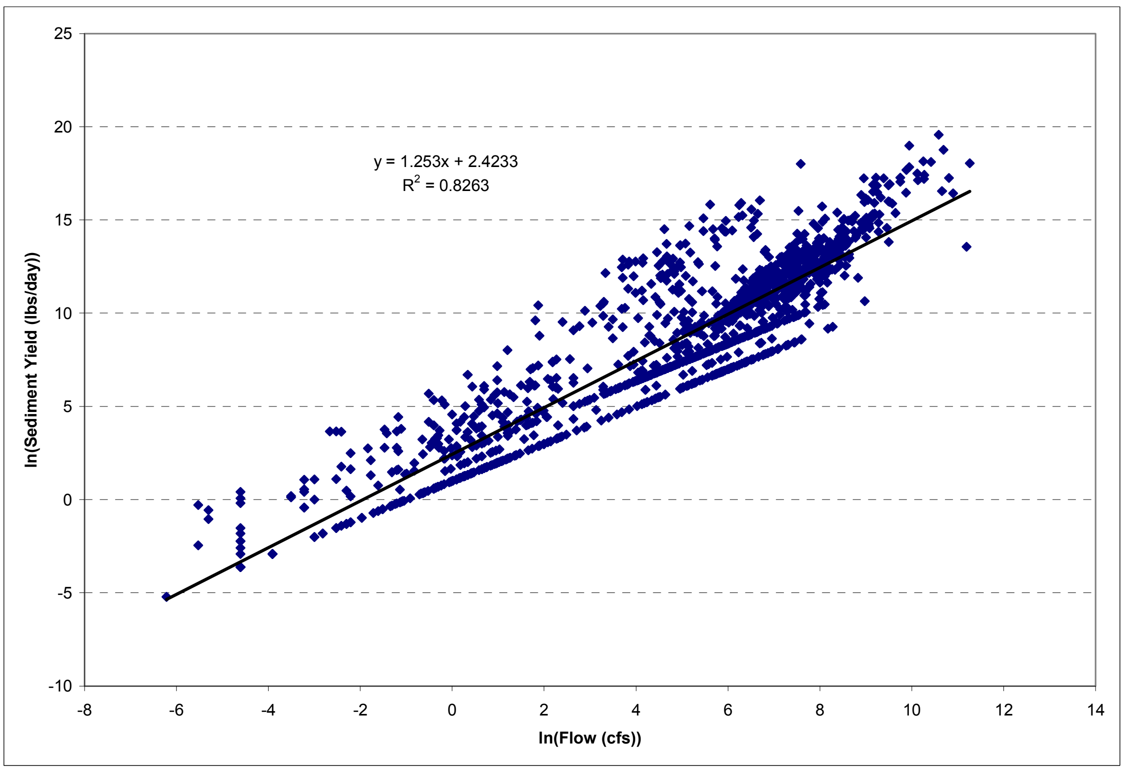


Figure C-2: Sediment yield as a function of instantaneous flow in Ozark/Meramec EDU.



The load duration curve was then calculated by back transforming the regression equation:

*Sediment yield (lbs/day)=exp(1.2538 * ln (flow) + 2.4233)*

This is then applied to the range of flows modeled in the FDC. For the metals, this some procedure is used, except that the target load is calculated directly from chronic limits in the water quality standards, based on hardness levels calculated for the EDU (see Appendix B of this TMDL).

To apply this process to a specific watershed, use the individual watershed data compared to the above TMDL curve that has been multiplied by the watershed area. Data from the impaired segment is then plotted as a load (lbs/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis. Results are in Figures 13-16 of this TMDL.

(Sources: USEPA 2006a, USEPA 2010 – See References section of this Pond Creek TMDL)

For more information contact:
Environmental Protection Agency, Region 7
Water, Wetlands, and Pesticides Division
Total Maximum Daily Load Program
901 North 5th Street
Kansas City, KS 66101
Web site: www.epa.gov/region07/water/tmdl.htm